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COMPUTER AIDED GEOMETRIC MODELLING OF CYLINDRICAL WORM GEAR DRIVE HAVING ARCHED PROFILE

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ABSTRACT

The objective of this publication is creation of computer geometric models (CAD) of developed in Diósgyőri Machine Factory and using exact production geometry first produced (grinded) cylindrical worm gear drive having arched profile by Illés Dudás [3, 4, 5] for connection analysis, Finite Element Method analysis, etc.
Since the worm and worm gear wrap each other, that is why the worm gear has to be produced by a tool geometry of which is similar to the worm geometry. Knowing of the Connection I. Statement tooth surface of driven element which is wrapped by driver element is defined by numerical calculations.
The CAD model of the worm gear could be designed by adaptation of interpolating B – spline surface to the tooth surface points of worm gear.

Keywords: worm, worm gear, hob, CAD, modelling

1. INTRODUCTION

One the most modern types of cylindrical helicoidal surfaces is the worm generated using a circular profile tool.
Contact surfaces between worms having ruled surfaces (Archimedian, convolute, involute types) and mated worm gears do not allow the formation of a continuous, high pressure bearing oil film. It is best to build up an oil film between mated surfaces so that the direction of the relative velocity of the drive faces into the direction normal to the common contact curve or very close to it [2, 3, 4].

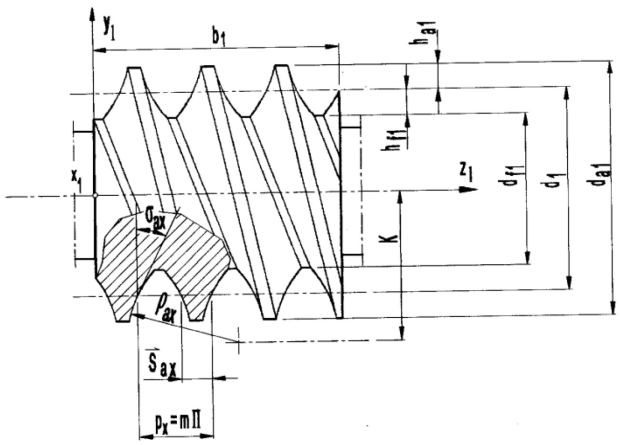

Figure 1. Cylindrical worm having arched profile [3]

A further advantage of mated elements having curved profile is that radius of mating flank surfaces are situated on the same side of the contact point common tangent, that is concave and convex surfaces are in contact, generating relatively small Hertz stress [2, 8].
As a consequence of smaller contact pressure, the load-carrying oil film can form easier.

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As a result of arched profile teething the tooth shape and the suitable positioning of the centre of curvature of tooth flank (the position of engagement line) the dedendum tooth thicknesses, both on the worm $\overline{S}_{1F}$ and worm gear $\overline{S}_{2F}$, are significantly wider [2, 6].

2. DEFINING OF COORDINATE SYSTEMS

The Illés Dudás type general mathematical model which is appropriate for mathematical modelling of production technologies methods is considered for defining of the necessary coordinate systems for modelling [3, 5].

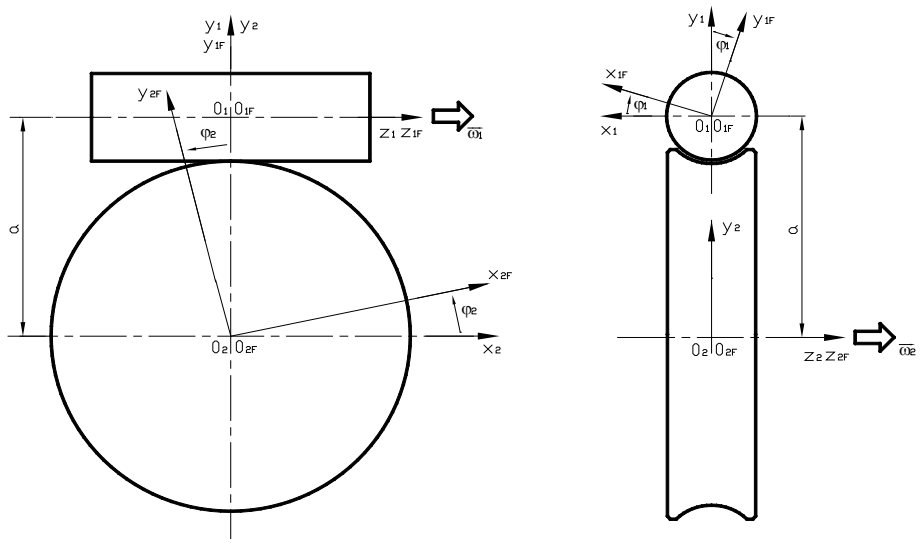

Figure 2. Coordinate systems dispositions for modelling of cylindrical worm gear drive

For the description of the motion relations we define the own motion of each coordinate system. Thus K_{1F} (x_{1F}, y_{1F}, z_{1F}) coordinate system rotates with

$$\vec{\omega}_1 = \frac{d\varphi_1}{dt} = const. \tag{1}$$

angular velocity in K_{1cs} (x_{1cs}, y_{1cs}, z_{1cs}) stationary coordinate system [3, 5, 7].

The K_{2F} (x_{2F}, y_{2F}, z_{2F}) coordinate system in the K_2 (x_2, y_2, z_2) coordinate system rotates with

$$\vec{\omega}_2 = \frac{d\varphi_2}{dt} = const. \tag{2}$$

angular velocity [3, 5, 7].

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Transformation matrices between the K_{1F} (x_{1F}, y_{1F}, z_{1F}) rotational coordinate system fixed to member 1 and the K_{2F} (x_{2F}, y_{2F}, z_{2F}) rotational coordinate system fixed to member 2 are (Fig. 2):

$$M_{2F,1F} = M_{2F,2} \cdot M_{2,1} \cdot M_{1,1F} = \begin{bmatrix} \sin\varphi_2 \cdot \sin\varphi_1 & \sin\varphi_2 \cdot \cos\varphi_1 & \cos\varphi_2 & a \cdot \sin\varphi_2 \\ \sin\varphi_1 \cdot \cos\varphi_2 & \cos\varphi_2 \cdot \cos\varphi_1 & -\sin\varphi_2 & a \cdot \cos\varphi_2 \\ -\cos\varphi_1 & \sin\varphi_1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$M_{1F,2F} = M_{1F,1} \cdot M_{1,2} \cdot M_{2,2F} = \begin{bmatrix} \sin\varphi_2 \cdot \sin\varphi_1 & \sin\varphi_1 \cdot \cos\varphi_2 & -\cos\varphi_1 & -a \cdot \sin\varphi_1 \\ \cos\varphi_1 \cdot \sin\varphi_2 & \cos\varphi_1 \cdot \cos\varphi_2 & \sin\varphi_1 & -a \cdot \cos\varphi_1 \\ \cos\varphi_2 & -\sin\varphi_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

3. GENERATION OF THE TOOTH SURFACE POINTS OF WORM GEAR

The dentation of worm gear is produced by hob which has similar geometry to worm connecting with worm gear based on the direct motion mapping [1, 2, 3, 4].
That is why we have to know the two parametric equations of the cutting edge of hob for modelling [3, 4]:

$$\begin{aligned} x_{1F} &= -\eta \cdot \sin\vartheta \\ y_{1F} &= \eta \cdot \cos\vartheta \\ z_{1F} &= p \cdot \vartheta - \sqrt{\rho_{ax}^2 - (K-\eta)^2} \end{aligned} \tag{5}$$

The tooth surface points of worm gear are determined by direct kinematic method. Knowing the cutting edge of hob and the Connection I. Statement we search the tooth surface points of worm gear which are generated by mutual wrapping.
The relative velocity vector is in the K_{1F} system:

$$\vec{v}_{1F}^{(12)} = M_{1F,2F} \cdot \frac{dM_{2F,1F}}{dt} \cdot \vec{r}_{1F} = P_{1k} \cdot \vec{r}_{1F} \,. \tag{6}$$

Based on (6) the derived matrix is:

$$\frac{d}{dt} M_{2F,1F} = \begin{bmatrix} i_{21} \cdot \cos\varphi_2 \cdot \sin\varphi_1 + \sin\varphi_2 \cdot \cos\varphi_1 & i_{21} \cdot \cos\varphi_2 \cdot \cos\varphi_1 - \sin\varphi_2 \cdot \sin\varphi_1 & -i_{21} \cdot \sin\varphi_2 & a \cdot i_{21} \cdot \cos\varphi_2 \\ \cos\varphi_1 \cdot \cos\varphi_2 - i_{21} \cdot \sin\varphi_2 \cdot \sin\varphi_1 & -i_{21} \cdot \sin\varphi_2 \cdot \cos\varphi_1 - \cos\varphi_2 \cdot \sin\varphi_1 & -i_{21} \cdot \cos\varphi_2 & -a \cdot i_{21} \cdot \sin\varphi_2 \\ \sin\varphi_1 & \cos\varphi_1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{7}$$

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The P_{1k} matrix of the kinematic motion mapping is:

$$P_{1k} = \begin{bmatrix} 0 & -1 & -i_{21} \cdot \sin\varphi_1 & 0 \\ 1 & 0 & -i_{21} \cdot \cos\varphi_1 & 0 \\ i_{21} \cdot \sin\varphi_1 & i_{21} \cdot \cos\varphi_1 & 0 & a \cdot i_{21} \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{8}$$

If η and ϑ parameters are independent from one another, then the normal vector can be calculated by the following way [2, 5]:

$$\vec{n}_{1F} = \frac{\partial \vec{r}_{1F}}{\partial \eta} \times \frac{\partial \vec{r}_{1F}}{\partial \vartheta} \tag{9}$$

The equations of the tooth surface of member 2 which can be defined as the mashing surface of the group of contact lines in the K_{2F} coordinate system [3, 7]:

$$\begin{aligned} \vec{n}_{1F} \cdot \vec{v}_{1F}^{(12)} &= 0 \\ \vec{r}_{1F} &= \vec{r}_{1F}(\eta, \vartheta) \\ \vec{r}_{2F} &= M_{2F,1F} \cdot \vec{r}_{1F} \end{aligned} \tag{10}$$

Knowing of the (10) equations we have worked out a computer program in case of a concrete cylindrical worm gear drive [2, 3, 5] for producing of the tooth surface points of worm gear (Fig. 3).
On Fig. 3 it could be seen the touched tooth surface points by the cutting edge of hob namely the tooth surface points of worm gear in the $y_{2F} - z_{2F}$ plane.

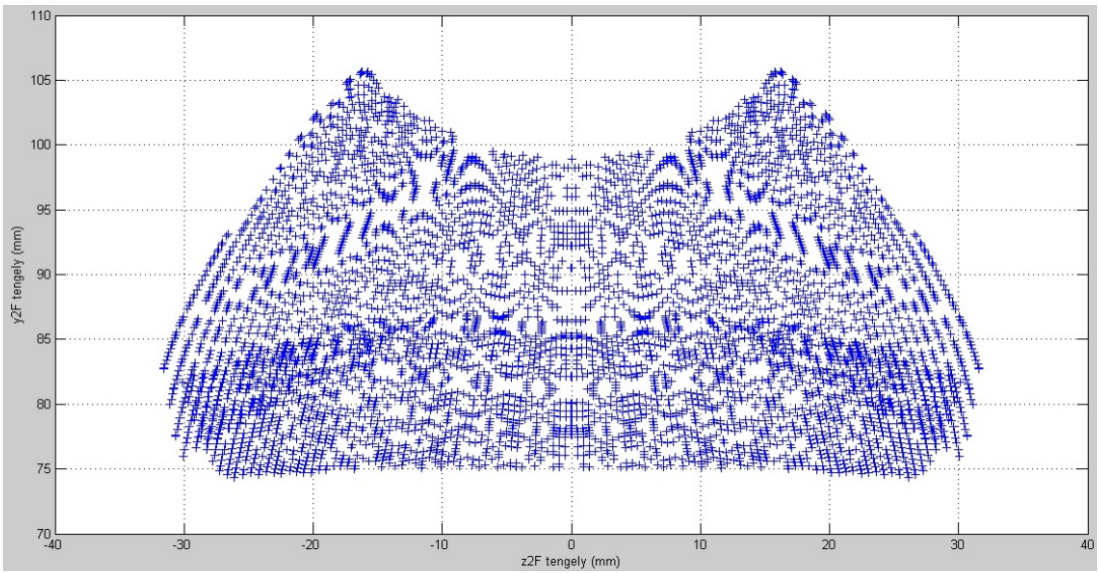

Figure 3. Determination of tooth surface points of worm gear

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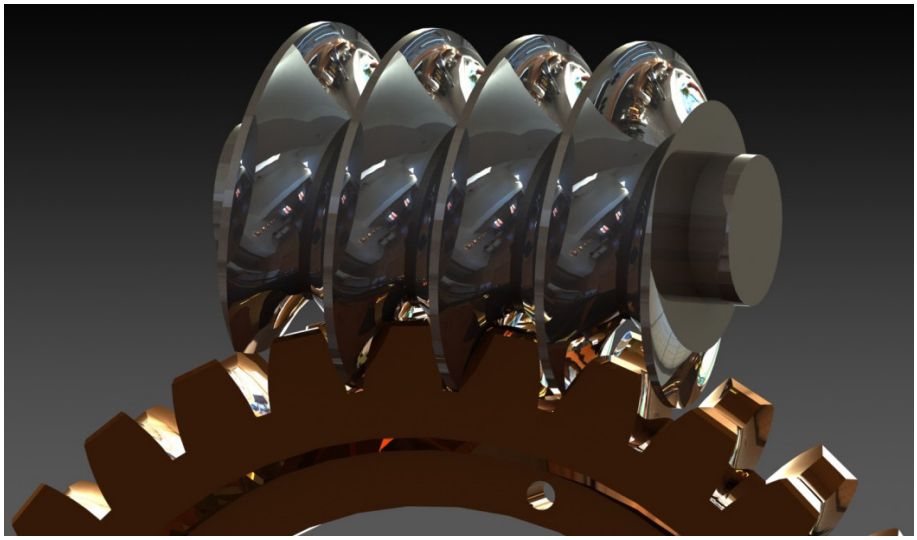
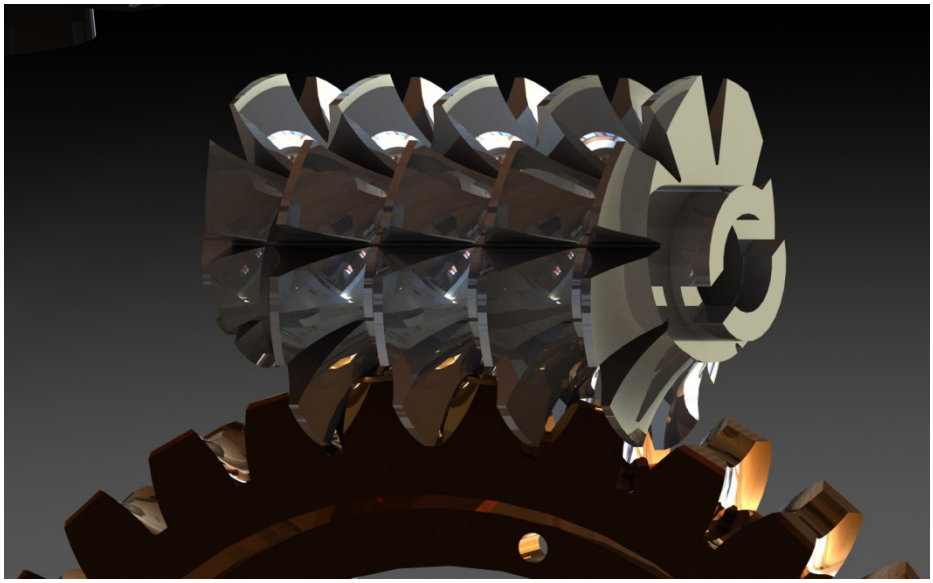
4. COMPUTER AIDED MODELLING

The generated TXT file by computer program is imported to Solid Works designer software.
On the profile points interpolating B spline was drawn, then tooth profile, along the circumference of the worm gear, was determined according to number of the gear cogs [1]. Limiting of the dentation territory has been occurred based on geometric data and technical drawing of the worm gear drive [2, 3].



a) Connection cylindrical worm – worm gear model



b) Connection cylindrical hob – worm gear model

Figure 4. CAD models of cylindrical worm, hob and worm gear

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Using the stated mathematical method for determination of the tooth surface points of worm gear, the worked out computer program and the Solid Works designer software the CAD models of cylindrical worm gear drive (worm, worm gear and hob) could be produced (Fig. 4).

5. CONCLUSION

The tooth surface of worm gear is determined by the worm dentation based on mutual wrapping. That is why in case of toothing the worm gear has to be produced by hob which has similar geometry to worm.
Knowing the cutting edges of the hob we have determined the wrapped surface by the hob by numerical way namely the tooth surface of the worm gear.
We have connected interpolating B – spline surface for the tooth surface points of worm gear and after produced the CAD models of cylindrical worm, worm gear and hob.
The received CAD model is suitable for other Finite Element Analysis and connection analysis.

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CUSTOMERS' OPINION ON THE MIZSE MINERALWATER IN KECSKEMÉT AND ITS NEIGHBOURING SETTLEMENTS

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ABSTRACT

In this article we studied one aspect of consumer's habit, namely the consumption of mineral water in the middle of Hungary. We applied so-called multiple methodology during the field work. We carried out a questionnaire survey as main method of research in CBA-supermarkets of three different settlements. The major part of the consumers considered the price as the most important factor of purchase. They beleived the secret of the success of 'Mizse' in it. The interest in the pack of 0.5 litre was surprisingly great. The product of this size of packing has been released later. Almost 58% of the costumers buying 'Mizes-water' would certainly try the fizzy drink called 'Mizse-lemon soda', too. The initial results echoe the need of further investigation.

Keywords: mineral water, packaging, consumption behaviour, price, brand, factors influencing purchase

1. INTRODUCTION

We carried out our research in connection with the 'Mizse-water' of the company called Magyarvíz Ásványvíz Korlátolt Felelősségű Társaság (briefly: Magyarvíz Kft.) which water won „The Product of the Year"-prize in 2012 and 2013. What is the secret of its success? Its favourable price? Its mineral content? Its quality?
During our research we visited the company where we were welcomed helping us to compile the questionnaire and giving us the necessary statistical data.
The purpose of our research was to examine the reasons for the popularity of 'Mizse-water'. The relating survey was carried out in three different places (determined by the producer): in CBA-supermarkets in Kecskemét, Lajosmizse and Kerekegyháza. We accomplished our survey on 5th and 7th June, 2014 in Kecskemét, on 14th June in Lajosmizse and on 21st June in Kerekegyháza. We had the following hypotheses:

- The packaging of 0.5 litre would be popular among costumers. Perhaps 2/3 of the respondants would buy it. (It was not sold at the time of the survey.)
- We assumed that the most influencing factor of purchase (the custumers' s decision) would be the price of the products. It is followed by the good quality and then the placeof origin as a sort of local performance.
- At least half of the respondants would buy the 'Mizse-lemon soda' product.

We intended either to prove or reject these hypotheses.

2. LITERATURE OVERVIEW

According to the surveys carried out by the European Federation of Bottled Water (EFBW) the consumption of mineral water per person was 104.3 litre as an average in the EU-24 countries in 2012. The highest indicators were in Italy (180.5 l/person/year) and Germany (177.1 l/person/year).
Hungary performs nearly average results in Europe. One person consumed 117.8 l of mineral water in the given year which means that our country is ranked to the fourth place in the EU-24 countries. The annual consumption was 3 l/person/year in the 1980s and at the beginning of the 1990s. The consumption started to grow dynamically –by 20-30 % per year- in 1993 and then in 2012 it reached the 118 l per person [1] [2].
In 2002 the companies Danone and San Benedetto founded the Magyarvíz Kft. as a green-field investment near Lajosmizse, by the motorway M5 [3] [4]. The production started here in 2003. The firm has achieved

a number of outstanding classifications during the years which managed to rise its success: ISO9001-2009, the prize „Product of the Year" 2012/2013, IFS2012 (International Food Standard) [5] [6]. On the basis of the national sales data 'Mizse' is the fourth most popular bottled mineral water in Hungary. In 2012 it reached the increase of 60% in the category of cheap, 50-70 fts products in hypermarkets which was partly due to the fact that the product family won the prize „Product of the Year" [7]. According to the statistical data, it can be said that it was the Magyarvíz Kft which could reach the highest increase related to sales between Octobers of 2012 and 2013 with a value of 21%. The data of August reflects the success again: the non-carbonated version of 'Mizse' is among the first five most popular bottled mineral water on the fourth place while the carbonated one is on the fifth place. Both of them show an increase in the examined period. (17,5%, 0,5%)[8].

3. MATERIAL AND METHODS

We used both secondary and primary research methods in our work. The secondary research involved a short presentation of changes in consumption of mineral water in the European Union and Hungary, also we could have a look into the history, success and market position of the Magyarvíz Kft. Our primary research was carried out in the framework of a questionnaire survey. According to Bércziné [9] the most important methods of primary research are the inquiry, observation, experiment and the so-called other primary researches. We can distinguish qualitative and quantitative data collection: experts consider the qualitative methods generally more authentic while the quantitative methods more precise [10] [11]. We compiled the content of the questionnaire according to the methodological descriptions of Kotler and Keller [12], Malhotra [13], Scipione [14] and Magyar [15].
The questionnaire contains altogether 22 questions. Some of them are of demographical type, and the others are aimed to examine the opinion and satisfaction of the costumers. Following the principle of progressivity we started with general questions which related to the frequency of the consumption of mineral water, to the well-known brands and to other aspects. After that, we focused the questions to the product family 'Mizse'. We involved questions preferred by the company like for example packaging and questions about 'Mizse-lemon soda'. We finished the questionnaire with demographical questions which connected to the place of residence, educational attainment, sex and age.
We used the program SPPS Statistica, which helps process more complexed data basis quickly and effectively, to process and evaluate the questionnaires. The program involves a wide range of statistical methods: data base, descriptive statistics, other multi- variables statistical methods [16].

4. DESCRIPTON AND EVALUATION OF THE RESULTS

Altogether 252 people completed the questionnaire. Their composition by sex are as follow: 61% were women, 39% were men. Most of the customers ranked to the age group 50-62 (60 people, 24%).
Almost half of them (45.23%) drink mineral water more times a day, 26.19% on a daily basis, 17.46% on a weekly basis.
The most frequently consumed mineral water brands chosen by the respondants were Natur Aqua, Szentkirályi, Zafír, Mizse, Theodora, Nestlé Aquarel. Besides, they named other brands, too, in a much smaller number: Emese, Jana, Verde, Vöslauer, Knjaz Milos, Balfi, Aquarius.
Only 66% of sample (166 people) think that it is important to drink national mineral water.
84.52% of the respondants know and 79% of them buy the bottled water called 'Mizse'. However, exactly the opposite can be observed in the case of 'Mizse'-tea. 92% of the answerers did not know the tea among the products which can be due to the fact that the firm does not really advertise its products. Only 56% of the people know the 'Primavera', while 68% of them the 'Zafír-water'.
Most of the customers purchase the 'Mizse' mineral water every week. 79% of the respondants choose more frequently the one in the 0.5 l packing.

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What other packaging would be the subject of the customers purchase? 37.5% of them would like to see the one of 0.5 l, 25% the bottle of 2.5 l and 13% the pack of 5 l (Fig. 1).

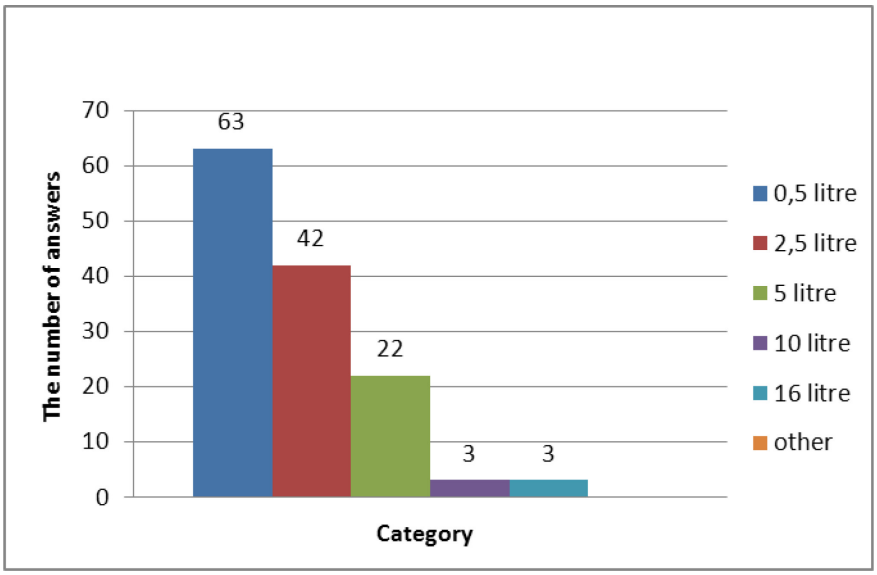

Figure 1. n=168) What other packaging would the customers like to purchase the 'Mizse' water? (n=168) The number of answers/ Categories/litre/Other

Our next question was directed to explore how the customers see the quality of the 'Mizse-water'?
The answers reflectwhat the customers think about the quality of the 'Mizse-water'. 92% of them ranked it either to the category of medium or better. Within these three categories most people chose the 'good'one: 57% of the answerers chose this option. About a quarter of them considers it medium, while 10% outstanding.
For the respondants it is the price which influences most their choice, the mineral content and the place of origin were ranked to the second position, while the name of the product and its producer do not influence them.
Would you try to taste the 'Mizse-tea' or the 'Mizse-lemon soda'? The opinion of consumers of 'Mizse' mineral water is almost equal in connection with the tea. 53% said yes, 47% no. 58% of the respondants would try to taste the 'Mizse'-lemon soda, while 42% of them would not choose it, if it were released.
Which flavour would you choose, if you tried the tea?
The most popular flavour would be the lemon (43%), it was followed by the cranberry-flavoured tea (37%). The green tea occupied the third rank which would be bought by 34% of the respondants. The popularity of peach flavour was under 30%. The less popular tea was the black one: only 11% would try this product. Other flavours were not mentioned in the survey.
How much would you pay for the tea or the soda (a bottle of 1.5l), if you tried it?
36% of the answerers would pay a sum between 100 and 130 fts for the tea. About the same amount (17 and 20%; 15 and 18 people) chose either less than 100 fts or a sum between 130 and 160 fts for the bottle of tea. About 6% would pay between 160 and 190 fts for this sort of product.
Similar to the tea, most of the answerers chose the second category for the soda: 37% would pay a sum between 90 and 100 fts for this product. 13% less than 90 fts and 18% a sum between 100 and 110 fts. Only 9% would pay between 110-120 fts for the 'Mizse'- lemon soda.

5. SUMMARY

The result of our research according to the opening hypotheses.

1. According to our hypothesis the packaging of 0.5 l would be popular amongstcustomers, more than two thirds of them would buy it. The survey shows different results. Only 38% of the customers would purchase this packaging, thus the hypothesis has not been confirmed. Although this 38% can be regarded as an important demand which was proved by the fact that the packaging of 0.5 l has been launched in the market since the survey.
2. The hypothesis claims that the most influencing factor for the purchase is the price of product [17]t is followed by the mineral content and then the place of origin. It was partly proved to be true: in our survey we could experience that the most important factor is the price level. The mineral content as one of the quality indicators and the place of origin as local product [18] were ranked to the same place.
3. The hypothesis assumed that at least half of the consumers of the ’Mizse’-water would try to taste the ’Mizse’-lemon soda, as well. Almost 58% of the consumers said that they would try the above-mentioned product if it were in the market. This hypothesis has been confirmed.

During our research we observed that most of the customers appreciate the ’Mizse’ mineral water of a good quality. It has also been proved that the price of the product is the most influencing factor for the answerers. In our opinion the popularity of the ’Mizse’- water embeds in these two factors: the costumers buy it with pleasure because they can get a product of a good quality for low price level. Provided the firm is still planning to produce tea, it would be practical to start with tea in flavours lemon and green tea. Our research underlined the assumption that more than the half of the respondents would try to buy the ’Mizse’-lemon soda so it would be a good idea to introduce it to the market.

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EDUCATIONAL APPLICATION USED TO SIMULATE THE FUNCTIONALITY OF A GASOLINE INJECTION SYSTEM

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ABSTRACT

This paper presents an educational application, with practical realization, regarding the functionality simulation of a gasoline injection system using a computer and a peripheral afferent, along with its control circuit. The application replaces the ECU (Engine Control Unit) and controls a demo injection rail, equipped with four gasoline injectors with different shapes of flow. The equipment provides the flow shape visualisation and injection parameters change according to the engine load conditions, which can be simulated by the electronic equipment through the virtual interface. The system allows the determination of the gasoline amount injected by the various types of fuel injectors, in a certain period of time and at different pressures of the fuel, depending on the load and the speed of the engine.

Keywords: gasoline injection, simulation, injection parameters

1. INTRODUCTION

The fuel injection in modern internal combustion engines is currently carried out exclusively under electronic control. In most cases, the control unit is represented by the "injection computer". This unit acts on the execution elements (injectors, spark plugs, motors, valves, regulators etc.) using signals which are influenced by the reaction parameters coming from the position sensors, speed, pressure, temperature, etc.
The complexity of the processes taking place in a system of fuel injection management for an internal combustion engine requires extra effort for a proper understanding of the operating principles. This is the reason for realising this paper, which is intended to be an intuitive practical application able to simulate the complex electronic control of injection, through a PC and specialized software. The application provides an intuitive and friendly analysis of the processes occurring during the operation of an injection computer.
The assembly is designed so as, via a PC running an application in the dedicated programming environment, to control an induction fuel injector rail through an electronic circuit with transistors, which communicates with the PC using the NI6221data acquisition board from the company National Instruments. In other words, instead of the engine control unit, it was used a PC running the virtual application and the NI6221data acquisition board, as peripheral for communication with the external components.
The difference relative to the input and output connections to the control unit is the fact that the acquisition of signals coming from the sensors is realised directly with the NI6221, without any intermediate circuit, and the injector operation benefits from 4 intermediate control circuits provided with bipolar transistors. Everything related to the acquisition of signals from the sensors and generation of signals from the processing unit becomes the task of the two elements.
The assembly described above – consisting of two distinct parts: the software (represented by the virtual application, which controls the injector opening) and the hardware (represented by the fuel circuit and injector rail) – is intended as an experimental stand with exclusive didactical applicability. The aim is to observe the main characteristics of a fuel feeding and injection system, as follows:

- identification of components for the control system, data acquisition and generation system, and fuel injection system;
- analysis of the different types of signals that can be used to actuate the injectors;
- establishing the principles of injector operation in accordance with the control electronics;
- visualization of the injection cadence and amount injected, depending on the engine speed and load;
- programming of injection computers.

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2. APPLICATION HARDWARE DESCRIPTION

The hardware assembly is made of various devices and modules, i.e. the PC, the NI6221 communication peripheral, the control circuit with bipolar transistors (BD237 and BC107, respectively), the rail with 4 different types of injectors, the fuel pump, the litrometric probe, accelerator pedal and power supply.
Taking into account the component elements and their functional role, it was realised the diagram of the fuel injection system, shown in Fig. 1.

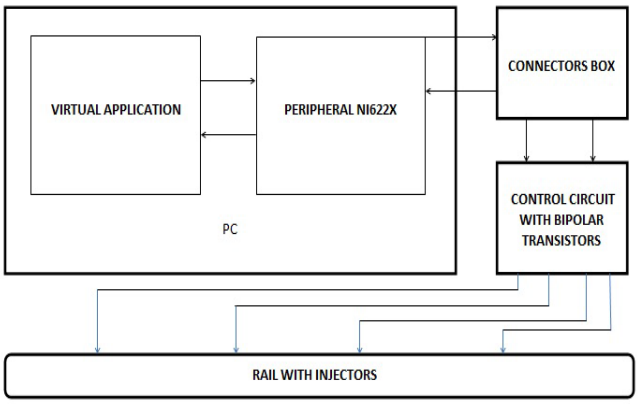

Figure 1. Functional diagram of the application

For easier identification of the experimental stand components, it was chosen a solution that enabled us to easily observe and even disconnect all the components. Based on the geometrical shape of a fuel rail fitted on the Opel Astra G engine, made in 2007, it was designed a container in which the injectors supply gasoline, container that enables us to watch the quality of the pulverized fuel flow shape.
Moreover, the device contains four tubes for the quantitative determination of fuel consumption, at different regimes of engine operation and various rail pressures.
To see the shape of the injector nozzle heads, it was designed a system that enables the common rail to rotate around its horizontal axis.
In order to obtain variable pressures on the supply line and on the common rail, the fuel pump was connected to a circuit which, by reducing or amplifying voltage, decreases or increases the pressure.
In order to get the exact moments for triggering the fuel injection and, especially, the time interval within which the injectors spray the fuel, they are connected to a circuit simulating the injection computer.
The source of DC voltage, ensuring the supply of necessary energy for the electronic control circuit, litrometric probe and fuel pump, is provided with three pairs of terminals which are able to provide adjustable pressure to two of them, and a DC voltage of 5V to the other one.
Besides the software, the PC assembly includes also a physical part, represented by the data acquisition board. It communicates with the other components through the connector block, where the control terminals for each injection circuit are connected.
The electronic control circuit is the element that transposes the signals generated by the data acquisition board and modelled by the virtual application in useful signal, able to command the injectors to carry out the fuel spray.
The injectors are placed on the common rail, where the fuel is brought from the tank, previously passed through a pressure regulator which is intended to maintain the rail pressure within a certain range.
The fuel tank houses the electric fuel pump, the level sensor with mobile buoyant, element that converts the level into a set of electrical parameters in the form of an adjustable resistor with cursor.

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The command originating from the accelerator pedal was realised through a USB port, providing a signal to a wide range of values, in progression, that increase according to the pedal pushing force. The entire assembly is interconnected. Fig. 2 presents an overview of the application hardware.

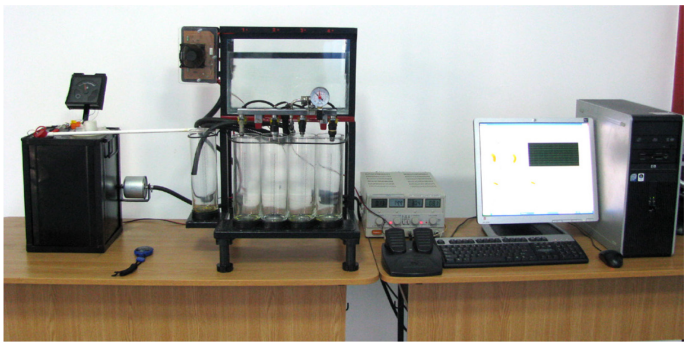

Figure 2. Overview of the application hardware

3. DESCRIPTION OF THE VIRTUAL APPLICATION

3.1. The front panel

The front panel is the direct user interface for the virtual instrument in which operates, being provided with a toolbar and a range of control elements (Fig. 3).

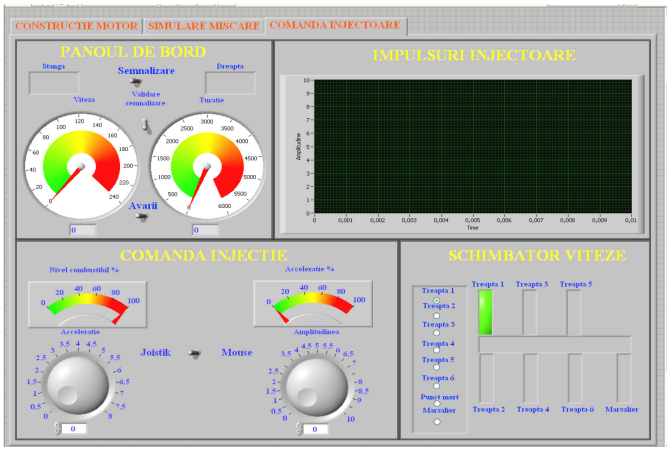

Figure 3. Overview of the front panel

The user can change the input value for certain parameters, or view the value generated by a virtual instrument, each control or indicator having a predefined datum type, to which it is associated, the most common being the numeric ones, of Boolean or string type. To display the processed data, it can be also used indicators of oscilloscope type, in which the different waveforms of the signals can be seen, whether they are digital or analogue.
As shown in Fig. 3, the front panel is divided into four sections, entitled “Dashboard”, “Injection control”, “Injector pulse” and “Gear shift”. In the subsection “Dashboard”, can be seen either the engine speed or the vehicle speed. The “Injection control” panel allows changing the engine speed (operation that can also be executed from the accelerator pedal), and its task. The “Injector pulse” panel allows viewing, in real

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time, the form of the injector control signal, and last but not least, the "Gear shift" panel allows simulating the gear changes, in accordance with the engine operating conditions.

3.2. Signal acquisition from the accelerator pedal

The accelerator pedal will be the frequency control element for controlling the injectors. In contrast with the other parameters of the signals, the signal provided by the pedal is controlled by a physical element, not a virtual one. The connection of the accelerator pedal to the PC is made via a USB port.
For the present application, it will be used a set of function blocks that will interface the signal given by the accelerator pedal with data types recognized by the utility tool.

3.3. Simulation of signals

The electronic control circuit of the injectors requires a continuous, rectangular pulse signal to instantly trigger the injectors of electromagnets, i.e. a voltage drop to close the injectors. This pulse signal has to maintain a certain cadence for each control circuit. The injection parameters will be changed by modifying the signal parameters.
This is implemented in the block diagram of the application. To simulate the signals, it was used the function "Simulate Signal" found in the program library. If the direct control is required, or during the process, the signal simulation parameters can be modified in real time by means of control elements placed on the front panel of the application.
For all the 4 signals that will control one circuit each and, therefore, one injector each, it was chosen control knobs. The need to have an input digital signal will require selecting the value of 5V for the peak voltage of the signal.

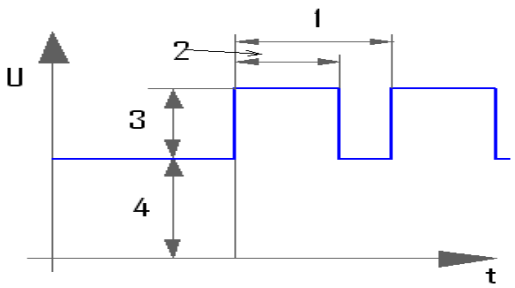

Figure 4. Components of the signal provided by the electronic control circuit

The components of the signal shown in Fig. 4 are: 1 – period, 2 – duty cycle, 3 – amplitude, 4 –offset.
The signal offset represents its position relative to the time axis. In the program, the offset value was selected to permanently be higher than 1, in order not to have the minimum amplitude of 0 V, for performance reasons.
The duty cycle is the pulse duration, being the parameter that directly affects the length of time when the injectors are open. This allows the fuel consumption control, whereas a higher duty cycle will result in spraying a greater quantity of fuel per cycle. This parameter is adjusted when the engine is subjected to a variable load. The duty cycle can be modified at the input "Duty Cycle" of the signal simulation instrument; it is expressed as a percentage.
The frequency control is achieved by means of the signal from the accelerator pedal, being acquired through the USB port and interfaced through the "Joystick Acquisition" module of the application. This parameter affects directly the engine speed, whereas a greater number of sprays in a given period of time will result in engine speed increase. If somebody wants to change the speed without changing the load,

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then only the frequency of the signal pulses will be increased, and if there is a greater mechanical load, then the duty cycle will be also changed proportionately.

4. EXPERIMENTAL MEASUREMENTS

The behaviour of the injection pump to the supply voltage variations can be established by determining the correlation between the voltage variations and the pressure values of the fuel supplied by the pump. As mentioned, changing the supply voltage of the injection pump leads to pressure change in the injector rail. The pressure is visualized by means of the pressure gauge fitted on the rail, and the supply voltage is indicated by the digital voltmeter afferent to the DC voltage source. The graph presented in Fig. 5 shows the variation of the pressure supplied by the pump versus the supply voltage of the pump.

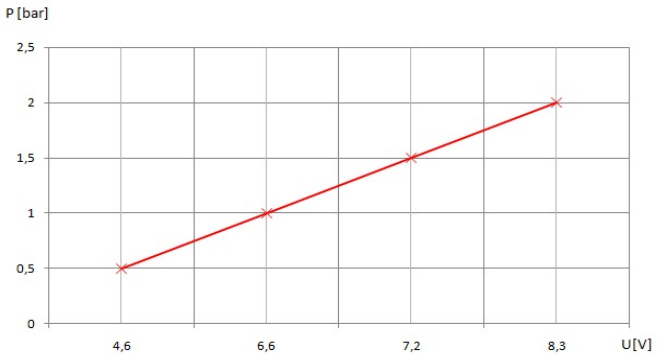

Figure 5. Variation of the fuel pressure versus the supply voltage of the pump

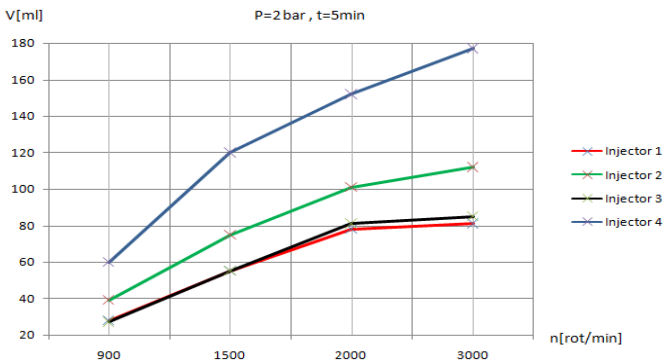

Figure 6. The injected fuel amount versus the injector speed and type

To reflect the structural differences among the various injectors, it was conducted a series of measurements that highlighted the different behaviour of the injectors to identical signals.
For example, it was decided to carry out measurements at a constant 2 bar pressure, at various simulated speeds. The cutting interval was 5 min.
It was measured the amount of fuel injected by each injector, for various speeds, at the same pressure supplied by the pump (Fig. 6).

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5. CONCLUSIONS

By making the application presented in this paper, were targeted the following aspects with didactic character:

- familiarization with the phenomena related to fuel injection into internal combustion engines;
- showing how the simulation of continuous pulsed signals realises the injector control;
- being available identical signals to control the various types of fuel injectors, it was revealed the structural differences among them in terms of quality and quantity;
- possibility to observe, in real-time, the form of the injector control signals in the assigned window, placed on the front panel of the application;
- possibility of measuring the flow rate supplied by each injector, by using a set of graduated tubes, in which the injectors are flowing the fuel;
- the observation of the fuel flow quality (geometric shape, number of spray holes, etc.) is facilitated by moving the injector rail in the top of the metal frame, where the glass bowl is placed, which is provided with return to the tank;
- a LED strip facilitates watching the moments when the injectors are flowing the fuel, the injector operation cadence in terms of speed, and the ignition order;
- by using the virtual development utility tool, we demonstrated how to realise complex simulation software without the need for "command line" programming knowledge, but only using diagrams with mathematical function blocks;
- in contrast to the similar stands on the market, it also offers a budget solution, the costs being substantially reduced if choosing this option instead of other brand products.

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EXAMINATION OF FOIE GRAS CONSUMPTION HABITS

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ABSTRACT

The goose liver is a special product produced by the force-fattened geese. The manufacturing process has thousands of years of history, which has grown to be a key sector for Hungary.
First, we intended to get to know the producers side on force-feeding of geese in the past and present during our research – this serves as a basis of structured interviews with 10 workers in the administrating sector. On the other side, we investigated the consumers' habits and opinions in relation with goose liver with a questionnaire. The first set of questions was directed specifically to consumer habits, including how often the product is consumed and why it is so. The second set of questions was intended to assess the knowledge on the process and other topic-related issues. Finally, we could establish that this type of products called 'hungaricum' is very important for Hungary because of the export and it also provides the basis for many farmers.

Keywords: structured interview, questionnaire survey, consumers' preferences, animal welfare

1. INTRODUCTION

Production of goose-liver has had an outstanding place in poultry products of Hungary for decades.
We are planning to show this field of interest from different aspects in our research.

1. we are aiming at giving a picture of both the past and present of the intensive liver-production,
2. on the basis of the direct opinion of people participating in production we are planning to get an inside view of the production,
3. furthermore, we want to assess the changes in consumers' habits, and we would like to get more information about people's knowledge on force-feeding of geese.

To achieve our aims we completed both quantitative and qualitative researches.

1.1. The story of goose fattening

Of all the poultry spieces what the humans domesticated the earliest was the goose, so goose farming can be regarded as one of the most ancient human traditions. Force feeding was applied even in the ancient Egypt (2500 BC.), there are pictures carved in or painted on gravestones and reliefs from 2500 BC. which show force fed geese.
This practice to fatten geese spread presumably from Egypt towards the Mediterranean region, first it was used in Greece then in the ancient Rome. After that, force feeding geese became well-known among the Jews where it spread all over Europe from.
According to certain researches, there are signs of this tradition which go back about thousand years in the Carpathian-basin. Goose farming has some hundred-year-old tradition in Hungary since geese were kept in the 10-11th centuries, too, after which church tenths had to be paid. The intensive goose farming started to develop in the middle of the 19th century which was due to the growth of corn production. Until the corn had not become a widely known fodder farmers used energy-rich plants to make the goose liver grow big and fatty. One of the most typical fodders was the fig which was the most basic solution. It resulted in a further development that goose farming on detached farmsteads and corn production linked together more and more tightly. As a conclusion it can be said that goose farming of Hungary significantly developed from the second half of the 70s as a result of which our country has been the largest producer and exporter of goose-liver in the world since 1980. [3] [6] [7]

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1.2. Challenges in animal welfare of the intensive goose-liver production

Goose-liver production is attacked on the basis of animal welfare issues, mainly it is the process of force feeding itself which is regarded as cruelty to animals. However, there is no scientific evidence even today to support this opinion. In countries which have great traditions of liver production, such as France, Hungary, Bulgaria, this sector employs a high number of workforce. Aggravation of regulations on animal welfare and different animal rights movements pose great challenges to the sector. Several countries in the EU prohibit force feeding, like Germany, Poland, Denmark, Estonia, Finland, Luxembourg. In these latter countries only Poland has a specific law to prohibit force feeding, while the others provide a general prohibition of force feeding. [3] [4]
The committee of agriculture and regional development of the European Parlament accepted the report relating to the EU animal welfare strategy for the period between 2012 and 2015 in June, 2012 but it refused the proposition on prohibition of fattened goose-liver.
We, Hungarians, have always considered force-fattened goose liver as our cultural and gastronomic heritage. In our country the Act XXX of 2012 was accepted in April, 2012 which defines the Hungarian national values and „hungaricum" as an indication of a value worthy of distinction which represents the high performance of the Hungarian people thanks to its typically Hungarian attribute, uniqueness, specialty. In the light of what criteria have been listed the goose-liver has a worthy place among other hungaricums. [5]
The organization called „Four Paws" is an animal rights organization, the seat of which is in Wien, that has started an international campaign against meat and liver coming from force-fed geese in November, 2006. It made a black list which included more Hungarian companies. The organization requested the supermarket chains not to buy products from companies which are on their list because they are involved in production of goods using the process of force-feeding. As a result of these measures, a certain situation took shape in 2008, which was also mentioned in the interviews made with the producers. The Hungerit Ltd. in Szentes suspended the manufacture of force-fed goods as they had lost their Austrian and German markets of great significance. The so-called discrediting campaign caused a serious damage –worth of some thousand millions forints- for the company and they had to dismiss hundreds of employees. The Hungerit Ltd. sued the Four Paws for damages but as the first step they wanted to be removed from the list. [8] The emotions became determinant factors, although the question of food quality and food safety should have been emphasised. [2] The responsibility of media is to be highlighted; however, in this present case the sensation-hungry media ignored the reality from time to time.

1.3. Changes in production and export of the force-fattened goose-liver

Tab. 1 shows the changes in production and export of the foie gras between 2006 and 2012, year by year and indicated in tons. As it can be seen in the table the production grew up to 2008 then suddenly it stopped and then a regress can be experienced. Though this regress is not of that great degree as the data in the table suggest – due to the wage cut. As a result of radical animal rights actions the regress lasted up to 2012, however, the produced quantity grew again last year.

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Table 1. Production and export of the foie gras 2006-2012 among the members of BTT (ton) [5]

Year	Production (t)	Export (t)
2006	1 734,1	1 243,9
2007	1 947,2	1 318,5
2008	2 006,4	1 457,6
2009	1 556,8	1 173,6
2010	1 331,9	1 242,4
2011	1 190,6	1 205,5
2012	1 353,5	1 126,3

The quantity of goose-liver export shaped up according to what has been said above. The proportion of goose-liver of all geese reached its peak in 2009 with 45,2%, in the subsequent 2 years a regress can be observed, but in 2012 it exceeded the proportion of 40% again. In general, the goose-liver always approximated the value of 10% of all poultry export in the examined 8-year-long interval. Moreover, it exceeded this value in 2009 with the proportion of 12,1%. [5] It is worth to take into consideration that the loss in production or its artifical restriction in countries will be eliminated in short time since in the globalized economy of our era it is an easy logistic task to replace the missing product quantity. [1]

2. MATERIAL AND METHODS

During our work we carried out a double research in order to examine the subject from both sides. On one hand, we made structured interviews with 10 farmers whose main scope of activity is goose-fattening and production of goose liver; on the other hand, we intended to get more information on consumers' habits using a questionnaire survey. I accomplished this latter one in different types of settlements involving mostly the region of Southern Great Plains: in cities of county rights, also in towns and villages. The 18-year-old or older parts of the population of the settlements involved had the same chance to get into the survey. The questionnaire had the following groups of questions:

- Examination of the consumption frequency.
- Examination of the factors influencing the consumption. (occasion, price, healthiness)
- Quality and price sensitivity.
- Examination of attitudes towards the product.
- Examination of the knowledge about organizations related to the product.

The completed questionnaires were analyzed with STATISTICA program and EXCEL spreadsheet.

3. RESULTS AND THEIR ASSESSMENT

3.1. The results of the qualitative research

In connection with the interviews made with goose breeders we want to highlight three main problems. One of them is related to the *economic crisis* about which everybody clearly claimed that the expenses were growing and the rate of growth of the revenue is not proportional to the rate of growth of the

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expenses. They have to produce a lot more but the income does not grow. There were different opinions about the *increase of severity by the EU*. The proportion of yes-no answers was 40-60%. Those whose opinion was that the aggravation caused problems referred to the growing expenses of the changes prescribed by the EU. According to what they experience, the compliance with the regulations of the EU causes difficulties, moreover, extra expenses. To operate the given farm properly a number of authorizations (water permit, monitoring) are required the collection of which needs extra expenses again. They have to meet the requirements of the aggravation and regulations to keep the farm operable later in time, too. To solve them, they have to develop themselves which requires financial investments. These investments are based on the equity that is what causes the difficulties. Coming to *the current issues* livestock farmers listed the following problems: 6 of them underlined the rise in fodder and medicine prices, while 3 farmers mentioned the low purchase prices. 2 of them considered the higher expectations a problem, like the loss in demand and paying the employees, as well, together with the deterioration of the tamping material. One of them highlighted delaying payment as a current issue.

3.2. The results of the quantitative research

In the survey 150 people filled in the questionnaire, 67% women, 33% men – typically aged 26-40 (42%), 18-25 and 41-65 (27% - 27%)- answered the questions. Regarding their qualifications, 38% had university or college degree, 54% secondary school certificate, and 8% primary school certificate.
The first question of the questionnaire tries to find the answer to the frequency of goose-liver consumption. To determine the consumers' frequency we listed five options. The assessment showed that a significant part of the answerers (39%) consume the product 2 or 3 times a year, 23% only once a year. 19% of the answerers do not consume goose-liver at all because -as they said- they do not like this product. There is a relatively small number of those who have goose-liver every week. They are typically those who produce it or their family or friends fatten geese. The frequency of goose-liver consumption is rather influenced by its high price. Most people referred to their low income and that is why they cannot afford to buy goose-liver, some of them regarded this product beyond their reach.
Our second question is in tight connection with this subject when we asked the question about the occasions of the consumption. As possible options we listed Martin's Day (46%), Christmas (22%), a family occasion (29%), and no special occasion (75%). The category of „Other" (6%) involved those who said that they do not consume goose-liver, at all. The answerers could choose more options.
In the following, the answerers could read 5 statements in the survey. Their task was to indicate on a five-point scale how much they agree with the statements. On the basis of the answers it can be seen what image the consumers have on the goose-liver and products made of it. We calculated average and scatter from the points (Tab. 2).

Table 2. The consumers' opinion about the statements on goose-liver (N=150)

Statement	Average	Scatter
The goose-liver is a Hungarian specialty.	4,36	0,91
The goose-liver is a part of the healthy diet.	3,29	1,21
The goose-liver is unpayable for you.	3,01	1,16
The goose-liver is too fatty for me.	2,59	1,32
It is difficult to make goose-liver for me.	2,42	1,45

The answerers agreed mostly that the goose-liver is a Hungarian speciality, besides, it can be clearly seen that the product has a very high price so it is unpayable for most of them. For those who consume it it is

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not difficult to make the product – as the low point of the last statement shows. However, the consumers are not really aware of that the goose-liver is high in calories so it does not belong to the category of light food.

In question 7, which intended to examine how much the consumers know the *method of force feedin*g and its steps, we gave four options. The answerers had to choose only one of them. 47% of them is aware of the process of force feeding, and those who know exactly what process goes on in fattening the goose-liver are in an approximately similar number (40%). The proportion of those who do not know and do not want to know this process is 8%. They chose the option that they do not know it but want to know it in the smallest number (5%). (Fig. 1).

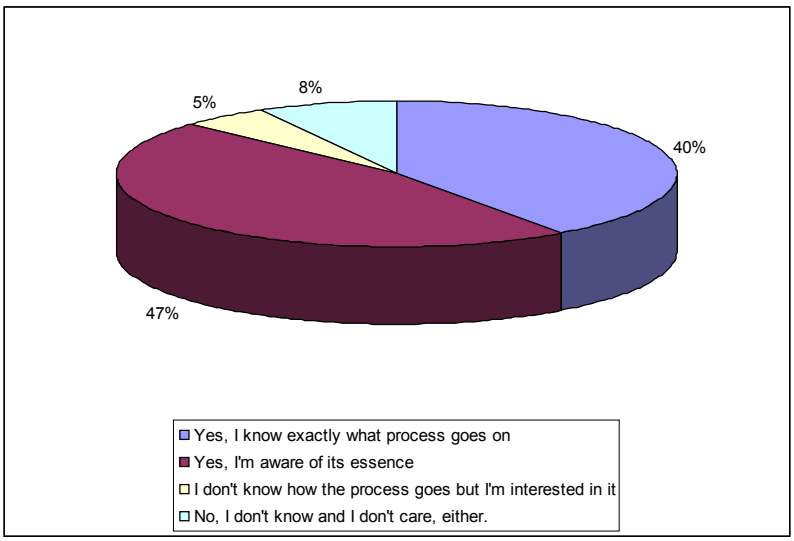

Figure 1. The knowledge of the process of force feeding geese

Distribution of answerers on the basis of how much they know about the process of force feeding geese, % (N=150)

In the following, we intended to examine the opinions on the organization *„Four Paws"*. 79% of the answerers have heard about them. The rate of the agreeing with the statements on them is shown in Tab. 3.

Table 3. Distribution of answerers on the basis of how the consumers see the activity of the organization called Four Paws (N=121)

	Average	Scatter
The activity of the organization results in decrease of production in the Hungarian goose sector.	4,19	1,19
The „Four Paws" damages the advantagous position of Hungary because it could reach it with the goose-live which is of „hungaricum"-character.	4,17	1,27
The organization is not about animal rights movement.	3,36	1,40
There should be more organizations of this kind, besides the „Four Paws" which protect animals.	2,21	1,43

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According to the data, most answerers judge the activity of the organization destructive.
The questions above were examined on the basis of demographic criteria, too. The following significant differences can be pointed out:

- In case of country and city dwellers we could find some differences in the question of how much they are aware of the process of force feeding. The number of people who live in the countryside is 33% of the answerers. 55% of them know the process exactly, 35% know the essence of the process, while 6% and 4% of them have the opinion that they do not know the process but are interested in it, and do not know the process and are not interested in it. 53% of the town dwellers are fully aware of the essence of the process but it is not totally clear for them. 32% have an exact knowledge on it, 5% do not know the process but are interested in it. The number of those who do not know how the goose-liver is produced and are not interested in it is 10% (Fig. 2).

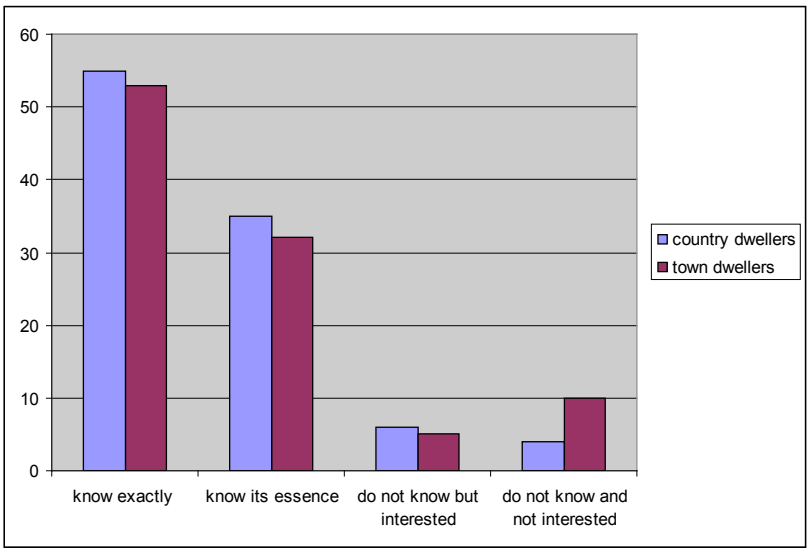

Figure 2. Distribution of answerers on the basis of the knowledge on force fattening among country and city dwellers (N=150)

- Everyone of those who finished their primary education has heard about the „Four Paws". 80% of those with secondary education and 75% of people with university degree could say that the „Four Paws" is not unknown for them. The reason for this apparent contradiction is that people with lower qualifications breed geese so this subject exercises more influence on them, while those with higher qualifications are not necessarily interested in it.
- Examining the distribution according to their dwelling places, 94% of the inhabitants of the countryside and 72% of the town dwellers said that the organization called „Four Paws" is not unknown for them. We can prove with this question that the town dwellers are less involved in this subject, so their indirect knowledge on it is more superficial, too.

4. CONCLUSIONS, SUGGESTIONS

On the basis of the research results, in case of the goose-liver and products made of it, it can be concluded that consumers' demands, their purchasing power and shopping habits are different according to their geographical position, age group and qualifications. Force feeding of geese is a widely spread process in the region of the Southern Great Plains, a lot of families earn a living from it. After assessing the results it can be said that people associate goose-liver to force feeding geese. Mostly country people associate to the process itself, they indicated in the largest number the answer that they exactly know what process goes on

in force feeding or that they are fully aware of its essence. Town people associate goose-liver rather to its taste. Most of them think of pate, fried goose liver and delicious taste when they hear the word „goose-liver". Accordig to the consumers'judgement goose-liver products can be sorted into the category of high prices, that is why their consumer group involve people with higher income. So, goose-liver has become a rarity since people can buy it only for high prices.

The answerers' opinion about force feeding as a process was generally similar. In most cases it is judged as an unavoidable evil. Nowadays, issues of animal protection and animal welfare are getting more and more emphasized even in our country. A small number of the answerers regards this process as cruelty to animals, it is typical for those who do not know the process itself.

Analysing the qusetion groups related to animal protection it can be concluded that only 21% of the answerers have not heard about this organization at all. Most of them agreed with the statement that the „Four Paws" damages Hungary's advantagous position which was reached the goose-liver of hungaricum-kind (4,17), and it causes the loss in production of the national goose sector (4,19). After questioning these 150 people, it turned out that 58% of them consume goose-liver or products made of it in different frequency. It can also be seen that those who do not consume goose-liver do so because they cannot afford it. The assessment clearly proves my earlier presumption that consumption of goose-liver is connected with some occasions in Hungary.

Its consumption can be improved by publicizing goose-liver in either gastro-TV shows or in festivals where people can get recipes or can taste it. The goose-feast on Martin's Day is popular in restaurants but menus could offer different choices on other days, too. Of course, the high price decreases the demand, but potential consumers who do not buy the product because of theoretical reasons (hostility against force feeding) can be persuaded with presentations, leaflets, brochures that this technology is not against geese. It is very important from the point of view of profitability, it can result in development of our national economy. It has a highlighted part in our export, besides, it provides the basis of several family farms and enterprises.

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FOOD SAFETY IN THE PUBLIC AWARENESS – SURVEY AMONG PRIMARY AND HIGH SCHOOL STUDENTS

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ABSTRACT

National and international surveys show that people still do not have appropriate knowledge of and attitude to food safety. Therefore more and more countries organize educational courses to improve skills and knowledge regarding food safety. In Hungary the National Curriculum 2012 contains the program for food safety education.
The aim of our survey was investigation about knowledge and attitude of primary and secondary school students towards food safety. The questions, according to international surveys, fell into 5 categories: personal hygiene, keeping food at safe temperatures, adequate cooking, avoidance of cross-contamination, and safe source of foods. Statistical evaluation was done using SPSS 20 software. Significant differences were evaluated by logistic regression, Chi square test, and crossing table analysis.
Results showed that there was no significant difference among primary school students regarding gender or residence (village or town) in knowledge of food safety. Their attitudes showed more significant divergence. Logistic regression investigation has showed that there was a good correlation between knowledge and attitude of personal and kitchen hygiene.
In conclusion, our students have presented more or less the same results as the others from international questionnaires. Even though, we need to improve knowledge and skill in food safety.

Keywords: attitude, food safety, knowledge, logistic regression, primary school, secondary school

1. INTRODUCTION

Importance of hygiene to avoid diseases has been recognized thousands of years ago. The Bible says people should wash their hands before eating and should not store meat in hot places because it could cause poisoning. In the 12th century Moses ben Maimon, a Jewish doctor, recommended not to consume uncovered and discolored meat [8]. Nowadays, in spite of general knowledge about the importance of hygiene, the incidence of food-borne illnesses is high. A FAO/WHO assessment in 1983 said that consumption of infected food caused most of the illnesses and the biggest expense around the world [3].
Consumers, being the last and very important element in the food chain, need to have adequate knowledge on food safety in order to minimize food-borne risk at home. Consumers' responsibility has been laid down in the directive of the Codex Alimentarius Commission, stating that consumers should learn the rules of hygiene and food handling [3], in the micro environment of family and in the macro environment of school. In Hungary, the National Curriculum 2012 includes education in food safety: teachers have to teach the rules of correct food handling and purchase [10].
According to literature data, the main causes of food borne illnesses are poor personal hygiene, cross-contamination, and insufficient cooking. Scientists therefore suggest that education should primarily focus on proper hand washing and avoidance of cross-contamination [6]. In the last decades a lot of countries began to teach people how to fight pathogens to reduce the occurrence of food-borne illnesses. The campaign called Fight BAC in the USA, for example, had four keywords: clean, separate, cook, cool [5]. In Hungary, the National Food Chain Safety Office (NEBIH) determined five basic rules: clean kitchen, clean water, safe raw material, clean hands, separation of raw and cooked food [9]. Besides these, the WHO also defines and suggests some rules: use raw materials from reliable source only; cook food thoroughly; eat prepared meal quickly; keep food at adequate temperature; eat leftover meal only after reheating it [3]. The kindergarten and primary school should be the first places for hygiene and food safety education.

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2. METHODS

The aim of our survey was to assess knowledge and attitude to food safety among primary school students, secondary grammar and technical school students, and their teachers. We searched for differences in gender, place of residence and age, and for correlation between attitude and knowledge. It was hypothesized that females, older people and urban habitants could perform better in our tests. Two set of tests was used, one for primary school students, and one for the adolescents and adults. All responders lived in South-East Hungary. Filling out the questionnaires was anonymous and voluntary, and the permission of school directors and parents had been obtained. The questions fell into 5 categories: personal hygiene, safe temperatures for food storage, adequate cooking, avoidance of cross-contamination, and safe source of foods. Questions from various national tests [2], [4], [7] were used and applied to Hungarian practice to create suitable questionnaires for our subjects. Knowledge of primary school students was tested with five yes/no questions, and their attitude, with 4 multiple choice (never, seldom, often, and always) questions. The yes/no questions covered all five categories while attitude questions covered three subjects: personal hygiene, cross-contamination and safe food storage temperatures. Children in this age usually do not cook or purchase foods alone thus questions regarding cooking and safe source of food were omitted from their questionnaire. The questionnaire for adolescents and adults contained 14 yes/no questions regarding food safety knowledge and 15 multiple choice questions regarding attitude. The knowledge questions include all topics: personal hygiene, adequate cooking, cross-contamination, safe food storage temperatures, and avoidance of unsafe source. The multiple choice questions covered all these categories, too.

2.1. Statistical analysis

Data were analyzed using SPSS 20 Statistical Package. Significance was determined at 95% ($P < 0.05$) level. Cross-tab analysis was used for percentage distribution of the variables. Chi-square analysis and logistic regression were employed to identify significant differences by gender and place of residence, and to explore the correlation between knowledge and attitude. The sum of true and false responses was converted to percentages.

3. RESULTS

Our questionnaires were filled out by 398 persons: 141 primary school students, 215 secondary school students, and 42 teachers.

3.1. Primary School Students

Among the 7-14 years old children who completed the questionnaire there were 72 boys and 69 girls, of whom 69 lived in towns and 72 in villages. Responses showed that more than 98% of the pupils knew, hand washing with soap is very important (Table 1). In Pennsylvania, for example, 15% of the students gave wrong answer to this question (Haapala et al., 2004). About 90% stated that dairy products have to put in refrigerator within 2 hours. On the other hand, about 40% thought that one should not isolate cooked and raw meat in the refrigerator, while in Pennsylvania the rate of correct answers was 91% [2]. The answers given to the question on the hazard of eating meals prepared with raw eggs showed that the pupils had limited knowledge about microbes and their role in food-borne diseases. Logistic regression and Chi-square analysis did not show correlation between knowledge and gender or place of residence.

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Table 1. Food safety knowledge statements among primary school students: percentage of correct responses

Knowledge statement	Correct answer	Boys %	Girls %	Urban %	Rural %
We should wash our hands with soap before eating	Yes	98.7	98.6	98.5	98.6
Meals made with raw eggs might cause illness	Yes	50.7	58.0	61.8	48.0
In the refrigerator we have to separate cooked and raw meats	Yes	61.6	56.5	61.8	63.0
Milk and dairy products should be chilled (refrigerated) within 2 hours to keep them safe	Yes	84.9	92.8	94.1	84.9
In improperly cooked meal dangerous microbes may be found	Yes	67.1	82.6	80.9	83.6

Schoolboys' attitude was better than their knowledge about food safety (Table 2). Most of them washed their hands before eating at home. Unfortunately about 20% of students did not wash their hands before eating in the canteen. In Pennsylvania only 29% of the schoolboys washed their hands at home and in the school canteen [2]. The logistic regression showed significant difference between genders according to washing fruits and vegetables before eating ($p<0.003$), and putting remaining food into the refrigerator within two hours ($p<0.004$). In both attitude question girls performed better.

Table 2. Results of food safety attitude questions among primary school students

	Often and always (%)				Seldom and never (%)			
Attitude statement	boys	girls	urban	rural	boys	girls	urban	rural
I wash my hands before eating at home	88.9	97.0	89.9	94.4	11.1	3.0	10.1	5.6
I wash my hands before eating in the school canteen	75.0	88.1	72.4	80.9	25.0	11.9	27.6	19.1
I wash my hands after stroking a pet	94.4	95.7	89.9	97.2	5.6	4.3	10.1	2.8
I wash fruits and vegetables before eating them	86.1	97.0	91.3	87.5	13.9	3.0	8.7	12.5
I put remaining food into the refrigerator within 2 hours	76.4	95.7	91.3	80.6	23.6	4.3	8.7	19.4
I have already had indigestion	4.2	7.3	46.4	6.9	95.8	92.8	53.6	93.1

3.2. Secondary School Students and Teachers

This questionnaire was filled out by 215 secondary school students: 134 boys and 81 girls. Concerning their residence 168 lived in towns and 47 in villages. The responses (Table 3) showed that the subjects' knowledge was inadequate in two topics: keeping food at safe temperatures, and avoiding unsafe source of food. These same problems were also recognized in other countries. About 60% of our responders knew that leaving leftover food on the table for hours is a food safety risk. However, in the United States, 89% thought that leftover hamburger without chilling was correct to eat [4]. These results showed that people have very limited knowledge about pathogenic microbes and their growth in food. Researchers suppose that 31 to 38% of food-borne illnesses are caused by keeping food at unsafe temperatures. This problem affects more than half million people every year [5]. About 80% of the subjects answered correctly that milk purchased directly from the farm should be boiled. Hungarian researches showed that consumption of raw food caused 6% of food-borne illnesses [1]. Logistic regression and Chi-square analysis showed significant difference between genders in questions to cooking with diarrhea ($p<0.026$), using the same cutting board for vegetables and raw meat ($p<0.004$), and separation of raw and cooked food ($p<0.049$).

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Boys knew better that cooking with diarrhea is not correct although generally they spend less time in the kitchen than girls. However, girls decided to separate raw and cooked food, and to use a new cutting board for vegetables. No correlation was found with place of residence.

Table 3. Food safety knowledge statements among secondary school students: percentage of correct responses

Knowledge statement	Correct answer	Boy %	Girl %	Urban %	Rural %
One should wash hands with soap before cooking	Yes	94.8	100	95.8	85.1
If one has diarrhea, it is okay to prepare food for others if one washes hands	No	61.2	55.6	60.9	42.6
Microbes are killed in hard-boiled eggs	Yes	80.6	81.5	62.5	70.2
Meals made with raw eggs might cause illnesses	Yes	69.4	76.5	71.4	57.4
Insufficiently cooked meat causes illnesses	Yes	61.2	56.8	65.5	53.2
One can use the same cutting board for raw chicken and raw vegetables if it is wiped off between uses	No	69.4	91.4	81.0	56.6
After touching raw meat, one has to wash our hands with soap before preparing other meal	Yes	78.4	90.1	81.0	63.9
In the refrigerator, cooked and raw meats need to be separated	Yes	89.6	98.8	91.1	83.0
Milk and dairy products should be chilled (refrigerated) within 2 hours to keep them safe	Yes	87.3	92.6	89.9	76.6
It is safe to leave leftover cooked meat on the table from lunch to dinner	No	65.0	65.4	69.7	51.1
It is safe to leave leftover pizza and hamburger on the table if it is eaten within 4-5 hours	No	28.4	38.3	31.6	27.7
It is okay to taste milk to check if it is still safe to drink	No	51.5	61.7	63.7	53.2
Dairy products with bulging cover foil are not useable	Yes	48.5	49.4	44.7	42.6
Milk directly from a farm has to be boiled before drinking	Yes	74.6	84.0	76.1	63.9

As to the attitude questions, some students do not wash their hands before eating in the canteen. Too little time for eating, and improper location of the wash basins, play presumably also a role in this situation. There are lots of false beliefs, such as the need to wash egg before putting in the refrigerator. On the contrary, washing the eggs will remove the protective layer which saves eggs against attack by microbes. Furthermore, there are only a few pathogens on the shell, the majority is found in deeper layers. Regularly, about 30% of the responders wash eggs before they put it in the refrigerator (Table 4). The frequency of cleaning the refrigerator is too low, which is dangerous because it could cause cross-contamination or pathogens growth. Logistic regression and Chi-square analysis showed significant difference between genders in terms of washing fruits before eating ($p<0.049$), washing eggs before using ($p<0.046$), cleaning the refrigerator ($p<0.024$) and having indigestion ($p<0.003$). Girls washed fruits and vegetables more frequently before eating than boys. More boys than girls have had indigestion because of the food consumed. This might be linked to other areas for example lack of personal hygiene, as boys wash their hands before eating or after stroking of pets less often than girls. Moreover they are more likely to consume

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meal with raw eggs or buy something from unofficial sources. There were significant differences according to residence: mainly urban inhabitants reported to never wash hands before eating in the school canteen ($p<0.043$) or after stroking pets ($p<0.035$) and some of them never put opened juice into the refrigerator ($p<0.035$). Correlation between knowledge and attitude was evaluated for frequency of hand washing and consumption of raw eggs. Logistic regression showed that only those persons answered that hand washing was important before eating who never missed out washing their hands ($p<0.000$) and almost always wash hands after stroking a pet ($p<0.045$). There was no correlation between knowledge about the risk of raw egg consumption and eating meals with raw eggs; this result showed that sometimes there is a gap between knowledge and attitude. Most people know that eating raw eggs may be risky but on the other hand eggs are considered a healthy food. Controlled, fresh eggs with sanitized shell might bring less risk to the consumer but under Hungarian circumstances most of the eggs are sold in markets from non-controlled sources. It is very important to provide people with information about Salmonella and causes of salmonellosis.

Table 4. Results of food safety attitude questions among secondary school students

	Often and always (%)				Seldom and never (%)			
Attitude statement	boy	girl	urban	rural	boy	girl	urban	rural
I wash my hands before eating at home	91.0	96.3	91.7	78.7	9.0	3.7	8.3	21.3
I wash my hands before eating in the school canteen	22.4	22.2	16.1	31.9	13.4	7.4	8.3	8.5
I wash my hands after stroking a pet	94.8	98.8	94.6	87.2	5.2	1.2	5.4	12.8
I wash fruits and vegetables before eating	77.6	95.1	82.7	72.3	22.4	4.9	17.3	27.7
I wash eggs before putting in the refrigerator	29.1	28.3	29.2	29.8	70.9	71.7	70.8	70.2
I put opened juice into the refrigerator	74.6	79.0	75.0	63.9	25.4	21.0	25.0	36.1
I put the remainder meal into the refrigerator within 2 hours	90.3	86.4	89.3	70.2	9.7	13.6	10.7	29.8
I eat only correctly cooked meat	96.3	100.0	95.2	85.1	3.7	0.0	4.8	14.9
I eat meals with raw eggs	24.6	17.3	19.0	38.3	75.4	83.7	81.0	61.7
I wash eggs before using	51.5	61.8	56.5	46.8	48.5	38.2	43.5	53.2
I buy goods from unofficial venders	14.9	8.6	16.1	12.8	85.1	91.4	83.9	87.2
I check the best before date of foods	76.1	86.4	79.2	63.9	23.9	13.6	20.8	36.1
I taste expired food if it is good for consumption	30.0	30.9	28.6	25.5	70.0	69.1	71.4	74.5
I clean the refrigerator at least monthly	73.9	55.6	69.7	72.3	26.1	44.4	30.3	7.7
I have already had indigestion	9.7	3.7	9.5	6.4	90.3	96.3	90.5	93.6

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4. CONCLUSION

Some of the obtained results are in contrast with our hypotheses. We supposed that females had more information about food safety but this was not proved by the results. Among primary school children, e.g., more boys knew that one has to separate cooked and raw meat in the refrigerator. Among the adolescents and adults, more males gave correct answer to the question about cooking with diarrhea. In the other questions, the attitude of girls and women was more appropriate, and it was verified by the results.
Regarding place of residence, people living in towns had more information and better attitudes than rural people but this difference was significant only in some cases. Statistic revealed, similarly to other researches, that older people had more knowledge and better attitudes than adolescents. There was a strong correlation between knowledge and attitude. The performance of our subjects was similar to the results of other countries, with more or less the same lacks of knowledge. The easiest way of improving knowledge is education in early life. Part of this education should be a practice in the school kitchen where students could learn how to prepare safe food at home. The electronic media (television, internet) could be a good mediator for adults by giving basic information about food safety. Elimination of the deficiency in knowledge and attitude deserved further efforts because these can cause illnesses and lot of expenses.

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IMPROVEMENT OF WATER VAPOR BARRIER PROPERTIES OF CHITOSAN-COLLAGEN LAMINATED CASINGS USING BEESWAX

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ABSTRACT

Collagen casings are commercially used in sausage production. In this paper, collagen film that is used for sausage casings was laminated with chitosan film to produce barrier casing film.
Chitosan coating was prepared by dissolving chitosan powder in 1% acetic acid. After dissolving chitosan, caraway essential oil, wetting agent Tween 20 and different amounts of beeswax, from 0 to 25 g were added to the solution. The solution was coated on collagen film surface in three layers, using a sponge brush to make laminated films. Films were air dried at temperature t =23 °C ± 2 °C. Uncoated collagen film was used as reference.
Film thickness, water vapor barrier properties and FTIR spectra were determined. With growing amount of beeswax added to the chitosan layer, film thickness grew from 112 μm for laminated film with 5 g of beeswax to 225 μm for film with 25 g of beeswax, compared to 83 μm for collagen film. Water vapor barrier properties improved with growing amount of beeswax in chitosan layer, ranging from 130.71 g/m^{2}24h for laminated film with added 5 g of beeswax to 66.96 g/m^{2}24h for the film with 25 g of beeswax, compared to 290.64 g/m^{2}24h for collagen film. Addition of beeswax showed great potential in lowering water vapor permeability of laminated collagen-chitosan film. FTIR spectra could be used to determine quantitative law dependency between added amount of beeswax and spectra absorption values,as well as to prove compactness of chitosan-beeswax layer.

Keywords: edible biofilms, chitosan, collagen casings, beeswax, characteristics

1. INTRODUCTION

Edible biofilms, which are produced from renewable resources, became trend in the development of packaging materials [19]. Among these films, polysaccharide films based on chitosan were extensively investigated. Chitosan is the name for a group of chitin substituents with low acetilation degree. Monomer units of glucosamine and a percentage of N-acetyl glucosamine in the molecule are linked with β-1, 4 glycoside linkage [5].
Chitosan got a tag GRAS (generally recognized as safe) by the FDA (Food and Drug Administration) in USA, as well as in Norway, Italy, Korea and Japan [25]. It is used in nutrition as a diet fiber, for lowering bad cholesterol level, help for lactose intolerance, and in food industry as emulsifier, color stabilizer, and neutralizer, flavor enhancer, for fruit juice clarification [14, 25, 30].
Numerous researchers proved chitosan antimicrobial, antioxidant activity, as well as its biodegradability [4, 29, 13, 14, 15, 21, 23, 24, 28, 33].
Because of the possibility to form films, chitosan was investigated in edible coatings and films production. Films showed good barrier properties to gases and good mechanical properties, while high water sensitivity remains an issue to overcome. These results varied in different reports, depending on the chitosan source and its features, used solvents and methods for producing the film, as well as the type and quantity of used plasticizer [14, 16, 31]. In order to improve the water barrier properties, the main lipid fractions incorporated into the base of biopolymer films are fatty acids [32, 35], vegetable oils [2, 6], hydrogenated oils [34] and waxes [11].
Chitosan can be used as a carrier for low molecular weight substances that are slowly released from the chitosan network. Many researches are working on active packaging design based on this principle [22, 5, 25, 30]. Antimicrobial and antioxidant activity of pure chitosan film may be improved by incorporating active compounds in the film matrix [8]. Plant essential oils can be considered as a natural alternative to chemical preservatives and their use in foods agrees with consumers demands for safe natural products with minimum chemical aditives [3]. However, wider application of essential oils in food industry is difficult to achieve due to their influence on organoleptic food properties and alterations of their natural

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activity due to interactions with food components [10, 26]. Caraway essential oil could serve as safe antioxidant and antiseptic supplement in preventing deterioration of foods [27].
Traditional collagen casings are mostly used for dry fermented sausage manufacturing. Regarding to manufacturing process, the desirable properties for traditional collagen casings are: allowing good penetration of flavors and aromas, water and steam permeability and resistance during filling and clipping. When sausage production is finished, further water lost, penetration of aromas and air oxygen becomes undesirable and shortens shelf life of the product [12].
For the above mentioned it might be useful to combine collagen films from casings with a chitosan coating, which should be a good barrier to gasses and protect the surface from microbial growth but its main drawback is sensitivity to moisture and its high water vapor permeability. In this paper, collagen film that is used for sausage casings was laminated with modified chitosan film to produce water vapor barrier biofilm. To improve water vapor barrier properties, beeswax was added to chitosan coating.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Coating preparation

Commercial highly viscous chitosan from crab shells was purchased from Sigma-Aldrich Chemical (St. Louis, Missouri, USA). Caraway essential oil was purchased from manufacturer Herba doo (Belgrade, Serbia), glacial acetic acid and Tween 20 were obtained from Superlab (Belgrade, Serbia).
Chitosan coating was prepared by dissolving chitosan powder in 1% acetic acid to reach chitosan mass per volume ratio of 4 $kg \bullet m^{-3}$. Solution was stirred overnight on a magnetic stirrer to dissolve chitosan. After dissolving chitosan, caraway essential oil and wetting agent Tween 20 were added to the solution in 0.8 % and 0.4 % volume concentrations, respectively. Different amount of beeswax 0, 5, 6, 7, 8, 9, 10, 11, 12, 15, 20 and 25 g was melted in 30 mL of distilled water on 65 ºC and added to filmogenic solution. Filmogenic solution was stirred for 5 min with laboratory stirrer and then coated on collagen film surface in tree layers, using a sponge brush to make laminated films. Films were air dried at temperature t = 23 °C ± 2 °C. Uncoated collagen film was used as reference.

2.2. Methods

Film thickness was measured using a micrometer Digico 1 (TESA, UK) with sensitivity of 0.001 mm. Eight thickness measurements were carried out for each film, and expressed as the mean value±standard deviation.

2.2.1. Water vapor transmission rate (WVTR)

Water vapor barrier properties of films were determined gravimetrically according to the ASTM E 96-95 desiccant method. Anhydrous silica gel was used to maintain a 0 % atmosphere inside the cells. Distilled water was used to maintain 100 % RH outside the cells.
The **ATR-FTIR** spectra were recorded at room temperature on a Nicolet iS10 FT-IR spectrometer (Thermo Fisher Scientific, MA, USA). All spectra were taken in the spectral range of 4000–500 cm^{-1} with a 4.0 cm^{-1} resolution. Software Omnic 8.1. and TQ Analyst (Thermo Fisher Scientific, MA, USA) were used to operate the FTIR spectrometer, collect and present all the data.
Statistical analysis was carried out using software OriginPro 8.0 SR2. Measurements of each property were made at least in three replicates. All data were presented as the mean value with their standard deviation indicated (mean ± SD). One-way ANOVA and Bonferoni tests, using a $p \leq 0.05$ level of significance, were applied to compare the means of properties.

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3. RESULTS AND DISCUSSION

Results for film thicknesses are shown in Fig. 1. With growing mass of added beeswax, thickness of laminated films grew. Good correlation ($R^2 = 0.9869$) could be withdrawn between these two parameters for the polynomial function of second order:

$$y = -0{,}0639x^2 + 7{,}4947x + 80{,}244 \quad (1)$$

This dependence could be also represented with linear function:

$$y = 5{,}844x + 87{,}894, \quad (2)$$

having correlation factor over 0.9 ($R^2 = 0{,}9791$).

With growing amount of beeswax added to the chitosan layer, film thickness grew from 112 µm for laminated film with 5 g of beeswax to 225 µm for film with 25 g of beeswax, compared to 83µm for collagen film without coating. Similar results were obtained when growing concentration of essential oils (lipophilic phase) was added to chitosan film. Chi reported that addition of 2 % oregano essential oil (OEO) in film-forming solution resulted in more than a 3-fold increase in film thickness [5]. In our previous work, we reported that lamination of collagen film with chitosan film without OEO didn't affect thickness of collagen film, but with OEO addition, thickness values increased significantly. Similar behavior was recorded for unlaminated chitosan films [17, 18].

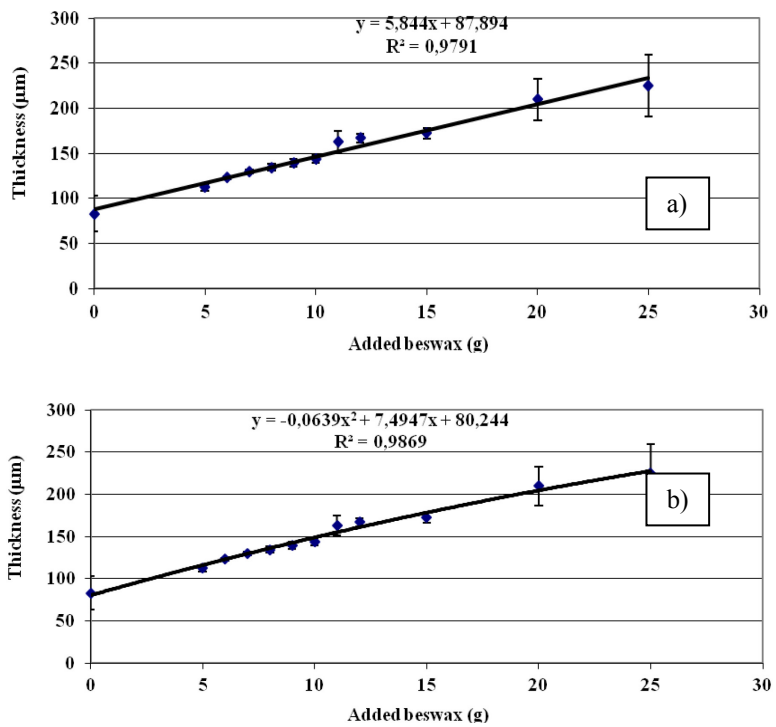

Figure 1. Thickness (µm) of laminated collagen-chitosan films with added growing amount of beeswax (g). a) linear function; b) polynomial function. Vertical bars represent standard deviation

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Water vapor transmission rate (WVTR) for tested films is shown in Fig. 2. Decreasing trend of WVTR with increasing mass of added beeswax can be observed. However, this decrease is not proportional to the added mass of beeswax. With the addition of 5 g of beeswax to the film, the most pronounced decrease in WVTR was recorded ($p < 0.05$), from 290.64 g/m^{2}24h for collagen film to 130.71 g/m^{2}24h for laminated film with added 5 g of beeswax (about 55% lowering). There were two more points where decrease in WVTR was significant ($p < 0.05$) and these points were for 10 g and 25 g of added wax, having WVTRs of 102.49 g/m^{2}24h and 66.96 g/m^{2}24h, respectively.

Addition of beeswax showed potential in lowering water vapor permeability of laminated collagen-chitosan film. Similar to our results, incorporation of lipolitic component into hydrophilic film was shown to lower water permeability. Oleic acid, pure or mixed with beeswax, had a plasticizing effect in the films and reduced water vapor permeability, compared to sodium caseinate film without lipids [9]. [2] succeeded in lowering the water vapour permeability (WVP) of chitosan-starch film using palm oil and margarine. Similar results with decreasing WVP of chitosan film were achieved with the incorporation of different lipid fractions (fish oil, vegetable oil, saturated fatty acid and unsaturated fatty acid) [31].

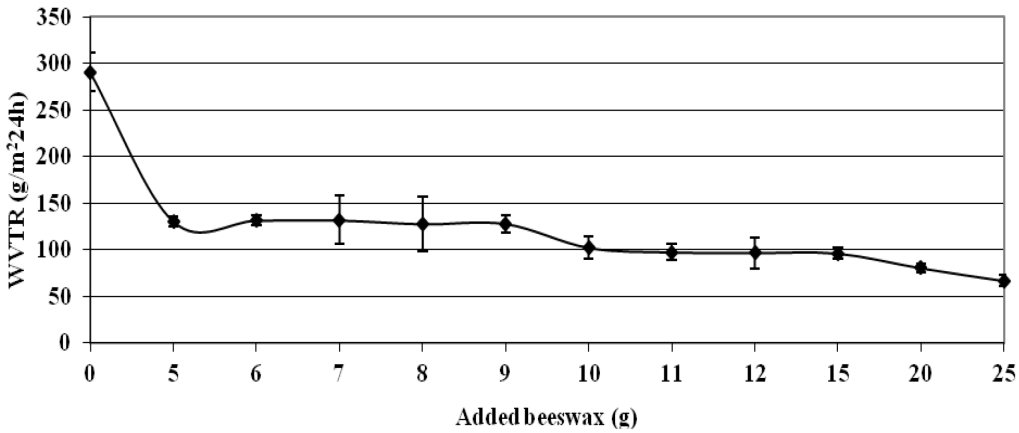

Figure 2. Water vapor transmission rate (g/m^{2}24h) of laminated collagen-chitosan films with added growing amount of beeswax (g). Vertical bars represent standard deviation

Fig. 3. shows collagen and chitosan-collagen laminated film with 5 g of beeswax in the chitosan layer, with their correlation. From the shown spectra it could be concluded that coating covered collagen casing completely. Correlation of 0.0801 shows that these are spectra of different materials.

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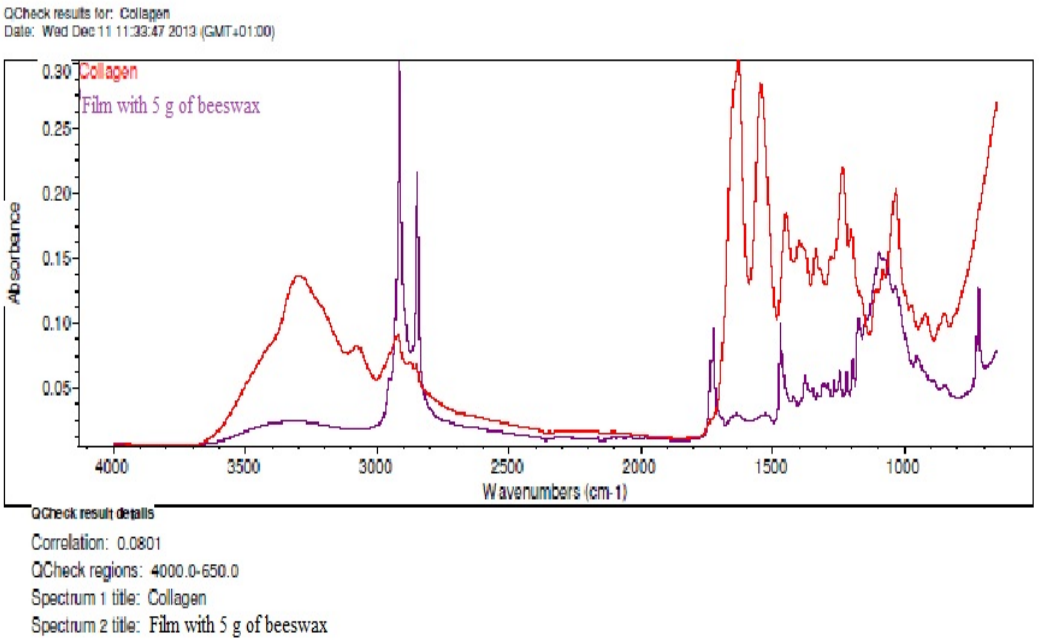

Figure 3. FTIR spectra of collagen and chitosan-collagen laminated film with 5g of beeswax in the chitosan layer, with correlation between the spectra

Spectra of collagen obtains a combination of four spectral intervals: ν(C=O) absorption of amide I (1,700–1,600 cm^{-1}), δ (CH2), and δ (CH3) absorptions (1,480–1,350 cm^{-1}), ν(C–N), and δ(N–H) absorptions of amide III (1,300–1,180 cm^{-1}), and ν (C–O) and ν (C–O–C) absorptions of carbohydrate moieties (1,100–1,005 cm^{-1}) [1].

For the laminated spectra with 5 g of beeswax, characteristic peaks for the chitosan spectra were identified: a broad band at around 3500-3000 cm^{-1}, for -N-H and OH•••O stretching vibration, as well as intermolecular hydrogen bonding of chitosan molecules, amide I and amide II absorption peaks (N-H bending vibration) at 1633.85 cm^{-1} and 1540.47 cm^{-1}, a band at 2920.17 cm^{-1} for $–CH_2$ asymmetric stretching vibration peak, a peak at 1407.68 cm^{-1} corresponding to -C=O stretching (amide I) and peaks at 1022.69 cm^{-1}, 1066.46 cm^{-1} and 1150.70 cm^{-1} due to –C-O stretching and –OH deformation vibrations [20; 36; 31; 7]. In addition to this, absorption bands appeared at 1736.28 cm^{-1}, originating from C=O saturated absorption and CH_2 scissor vibration band appeared at 1472.27 and 1462.59 cm^{-1} [36].

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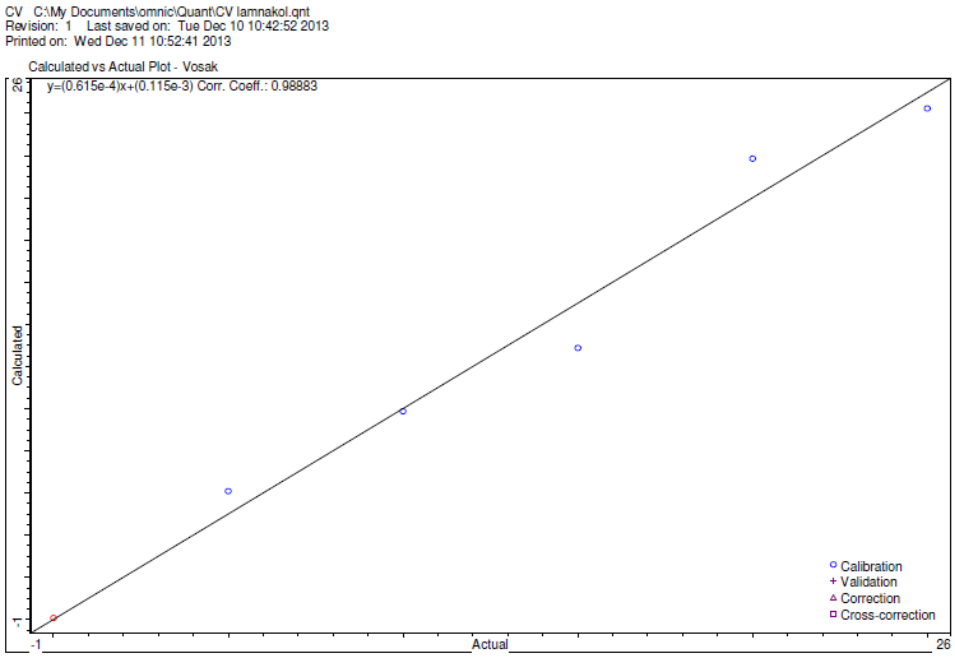

Figure 4. Calculated verses actual values plot for Simple Beer's law performed on spectra of laminated films with growing amount of beeswax

Using software TQ Analyst, quantitative analysis Simple Beer's law was performed on spectra of laminated films with growing amount of beeswax in the spectral region of 3871.40-3868.50cm^{-1}. Calculated verses actual values, shown in Fig.4 showed very good correlation (R^2=0.98883) for the linear function:

$$y=0.615e^{-4}x+0.115e^{-3} \quad (3)$$

Functional dependency, described by this equation, was determined between the amount of added beeswax and the FTIR spectra of laminated collagen-chitosan films with growing amount of beeswax in the chitosan layer, in the spectral region of 3871.40-3868.50cm^{-1}.

4. CONCLUSION

When growing amount of beeswax, as a lipophilic phase, was added to the chitosan layer of chitosan-laminated collagen film, film thickness grew significantly. Thickness grew for about 25% to 63% when different mass of beeswax was added. Addition of beeswax showed significant potential in lowering water vapor permeability of laminated collagen-chitosan film. Water vapor transmission rate was lowered up to 77% with the addition of beeswax. Functional dependency was determined between the amount of added beeswax and the FTIR spectra of laminated collagen-chitosan films. FTIR also showed continuity of chitosan-beeswax layer. Further work should be carried out to determine the effect that beeswax shows on other relevant properties of chitosan coating: sensory, mechanical and gas barrier.

5. ACKNOWLEDGEMENT

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INCREASING OF STIFFNESS OF DOUBLE-ACTING PNEUMATIC CYLINDER

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ABSTRACT

Position keeping properties of actuators depend highly on their stiffness. The low stiffness of pneumatic systems is well known, which is disadvantageous during positioning and when a position has to be kept. It is one of the reasons why hydraulic systems have advantages over pneumatic systems when it comes to positioning tasks. This paper deals with the analysis of the passive stiffness of a double-acting cylinder. The stiffness of pneumatic cylinders is derived as a function of chamber pressures determined by the bulk modulus of pneumatic systems. The stiffness of a passive system of the chambers is written by the pressure change through small displacement of the piston and as a result of the restoring force. In case of the passive system the effect of the valve actuation is neglected. From the deduction it is clear that the stiffness of a cylinder changes along the stroke, dead volumes at the end positions play a relatively important role. The results are compared with the restoring forces of the piston seals and other sealing elements in the stiction region. The restoring effects of the elastic elements were determined by measurements.

Keywords: pneumatic system, stiffness, friction, stiction

1. INTRODUCTION

The increasing positioning accuracy of pneumatic actuating units not only at the final positions, but also along the whole actuating track became an important research field during the last two decades of the 20th century. The investigations to improve the control algorithms of these so called “servo-pneumatic” systems usually in the centre of attention since the robust control of these systems is a rather complicated task because of the physical complexity of pneumatic systems. That is why, during the last couple of years many research groups are occupied with the dynamical analysis of servo pneumatic systems and are suggesting diverse algorithms to improve the positioning accuracy and the stiffness of these systems.
Based on new measurement methods and resulting statements, it is possible to increase the positioning accuracy and the dynamic properties of servo pneumatic systems. Considering this not only the improvement of control quality can be the aim of the recent investigations, but also the search for the reserves within the pneumatic system is a real life research task. According to this statement the dynamical modelling of complex pneumatic systems and the clarification of the relationships among the parameters are in the centre of the presented research.
The stiffness of the system plays an important role in the dynamic properties, because among other things this feature determines the resistance against forces and other disturbances when keeping a position. In contrast to mechanical propulsion systems (gearbox, toothed belt gear, worm gear, etc.) or hydraulic systems [1], pneumatic systems have a special feature because of the low value of the stiffness [2], [3].
The analysis of the pressure and the capacity of the chamber(s) is an important factor in case of rigid cylinder wall [3] and pneumatic muscles [4] as well. However the fundamental equations for stiffness description are well known, and many control strategies are developed based on the control of pneumatic stiffness [5], [6] but, the resulting spring stiffness, or the returning pressure of a double acting cylinder is not discussed. The focus of the research presented is the returning pressure determination of pneumatic cylinders.

2. MATERIALS AND METHODS

The two most important factors of passive resistance – without any correction by valve actuation – to external forces are the resilience of the pressure changes and the restoring action of the seals in the stiction

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region for small piston displacements. Several literature [2] [7] references indicate that the spring-like effect of seals in a close distance of the piston position causes forces acting against the load forces until the moment when the adhesion ceases.
The studies were carried out for the analysis of a rodless double-acting pneumatic cylinder type OSP-P-210-032-700 as shown on Fig. 1. The resulting restoring force equations from changes in pressure changes in chambers are valid for other double-acting cylinders, too.

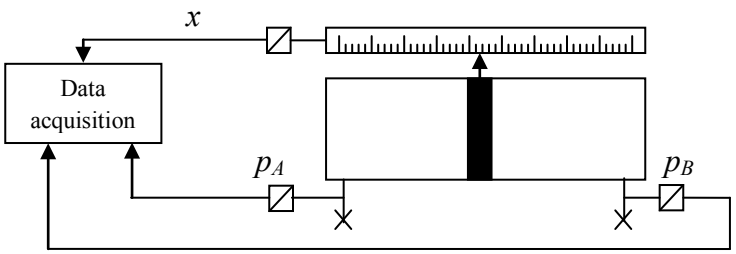

Figure 1. Measurement setup

3. RESULTS

Passive resistance of pneumatic cylinders against external forces can be defined by the resulting of two factors: resilience of the pressure changes and the restoring action force of the seals in the stiction region must be taken into consideration. Furthermore these properties are investigated.

3.1. Pressure changes in the chambers as a function of piston displacement

The chambers of the pneumatic cylinders behave as springs directed against one another. The stiffness of a material or structure is higher when the deformation from a given load is smaller. The modulus of elasticity or Young's-modulus E describes stiffness and elasticity. The connection for the description of the strain ε with respect to a stress σ for a load on the structure is:

$$E = \frac{\partial \sigma}{\partial \varepsilon} \tag{1}$$

In the denominator strain ε as the relative displacement can be described as:

$$\varepsilon = \frac{\Delta l}{l_0} \tag{2}$$

For linearly elastic materials (like many metals), Hooke's Law states, that the stress of a body to the strain in the elastic range is load independent. The modulus of elasticity in gases depends not only on the material properties, but also on the load, therefore further analysis is necessary.
The transformation of (1) is valid for pneumatic systems, as well. However, it is known as bulk modulus B instead of Young's-modulus E. The nominator of (1) represents the tensile or compressive stress normal to the plane usually denoted "normal stress" and can be expressed as:

$$\sigma = \frac{F}{A} \tag{3}$$

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Equation (3) describes the acting force F on the piston cross section A, which corresponds the pressure p for a pneumatic cylinder. For pneumatic cylinder with a piston surface A of this chamber is equivalent to a specific change in length, so equation (1) is as follows:

$$B = x \cdot \frac{\partial p}{\partial x} \tag{4}$$

To derive the bulk modulus a description of the relationship between volume change and the change in pressure is needed. It can be assumed that the cylinder cross-section is constant along the stroke length l_k, the volume of the chambers varies directly proportional with the displacement x. In the polytrophic process equation of ideal gases the volume V of the chamber can be written as a function of chamber cross section area and chamber length:

$$p \cdot V^n = p \cdot A^n \cdot x^n = const. \tag{5}$$

In case of isentropic processes, when there is no heat exchange between the gas and the wall of the cylinder, as it is in the presented case, the polytrophic exponent is $n = \kappa = 1{,}4$. If the piston is moving slowly the heat exchange generated through the walls of the chamber is unavoidable, in which case the polytrophic exponent value $n = 1$ for isothermal processes is used. As it is derived in [3], the Bulk modulus can be expressed from the total derivative of (5) as:

$$B = n \cdot p \tag{6}$$

Equation (6) shows that the bulk modulus of a double-acting pneumatic system (chamber) is not constant but increases linearly with the pressure. However a question arises, namely how big is the restoring force for a certain cylinder?

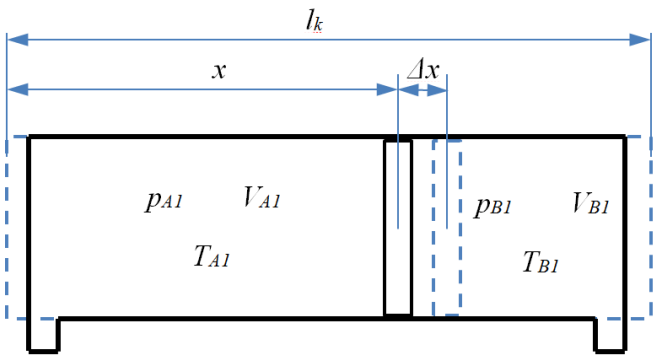

Figure 2. Principle diagram of the Pneumatic Cylinder state variables

Holding a position x means that the piston is in the appropriate position without any outside action, that means, the valves are closed. Accordingly the cylinder chambers can be considered as a closed system. For determination of the resulting spring stiffness along the stroke length of the double-acting cylinder the pressure changes should be specified in both chambers separately for small displacement Δx. Cylinders have addition dead volumes in connecting tubes and covers. In the calculation of the state change of compressed air these volumes must be taken into consideration as it is shown by the dashed line on Fig. 2.

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The restoring force ΔF against displacement of the piston is proportional. The stiffness of the chambers is derived from the polytrophic state equation for small displacements Δx:

$$p_{A1} \cdot A_A^n \cdot x^n = p_{A2} \cdot A_A^n \cdot (x + \Delta x)^n \tag{7}$$

$$p_{B1} \cdot A_B^n \cdot (l_k - x)^n = p_{B2} \cdot A_B^n \cdot (l_k - x - \Delta x)^n \tag{8}$$

The cross section of the pistons for both chambers does not change it can be used as a simplification. It is an important result that the chamber pressure does not depend on the piston cross-sectional area, i.e. the derivation of the change in chamber pressures applies to cylinders with piston rod and for rodless versions. The goal is to express the chamber pressure changes Δp as a function of the piston position x:

$$\Delta p_A = p_{A2} - p_{A1} = p_{A1} \cdot \frac{x^n - (x + \Delta x)^n}{(x + \Delta x)^n} \tag{9}$$

$$\Delta p_B = p_{B2} - p_{B1} = p_{B1} \cdot \frac{(l_k - x)^n - (l_k - x + \Delta x)^n}{(l_k - x + \Delta x)^n} \tag{10}$$

The numerator of (6) resp. (7) can be merged using Taylor series of $(x+\Delta x)^n$:

$$f(x) = (x + \Delta x)^n = x^n + n \cdot x^{n-1} \cdot \Delta x + \frac{n \cdot (n-1) \cdot x^{n-2}}{2} \cdot \Delta x^2 + \ldots \tag{11}$$

In the denominators of (9) and (10) Δx is relatively small compared to other coefficients, accordingly the simplifications $(x+\Delta x)^n=x^n$, resp. $(l_k-x-\Delta x)^n=(l_k-x)^n$ are possible. The resulting pressure change, or returning pressure Δp_F of the two chambers:

$$\Delta p_F = \Delta p_B - \Delta p_A = p_{B1} \cdot n \cdot \frac{\Delta x}{(l_k - x)} + p_{A1} \cdot n \cdot \frac{\Delta x}{x} \tag{12}$$

When there is no external force exerted on the piston, the pressures of the chambers are equal ($p_{A1}=p_{B1}$):

$$\Delta p_F = n \cdot \Delta x \cdot \frac{p_{A1} \cdot (l_k - x) + p_{A1} \cdot x}{x \cdot (l_k - x)} = p_{A1} \cdot n \cdot \Delta x \cdot \frac{l_k}{x \cdot (l_k - x)} \tag{13}$$

The returning pressure Δp_F can be expressed as a function of the chamber pressure p_{A1} or p_{B1}:

$$\frac{\Delta p_F}{p_{A1}} = n \cdot \Delta x \cdot \frac{l_k}{x \cdot (l_k - x)} \tag{14}$$

Equation (14) gives information of the relative return pressure in case of small displacements. Exact results cannot be obtained, because the state change can range from isothermal to adiabatic in relation with the heat exchange of the gas inside the chamber. The polytrophic exponent varies between 1..1.4 accordingly. However, according to the results the adiabatic state change approximates the process well.
The equation is not suitable for greater displacements. The reason is that for major displacements the exponential function of pressure change is described by a linear equation due the simplification by Taylor series. (11). Relative pressure changes caused by small piston displacements are shown on Fig. 3.

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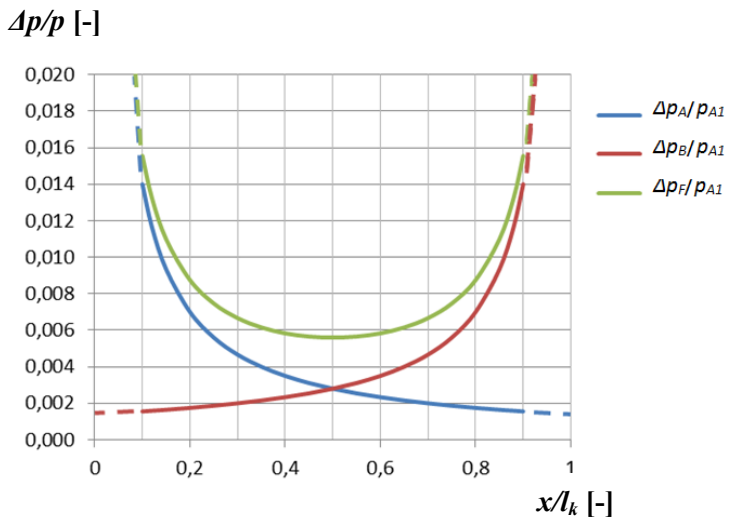

Figure 3. Relative return pressure (Δp/p) of the chambers at 0.1% relative displacement in relation to the total stroke

Figure 3 shows the relative return pressures of the chambers at 0.1% relative displacement in relation to the total stroke, which corresponds to a 1 mm displacement of a cylinder with a stroke length of 1 m. The dashed line represents the extended stroke length considered as dead volumes. Equation (15) determines the return force of the pressurized air for rodless cylinders.

$$\Delta F = \Delta p_F \cdot A = p_{A1} \cdot n \cdot \Delta x \cdot \frac{l_k}{x \cdot (l_k - x)} \tag{15}$$

When the task is not just positioning, but a certain force F has to provide by the cylinder the chambers must have different pressures. In this case manifestly $p_{A1} \neq p_{B1}$, so the simplification applied in (13) is not possible.

3.2. Restoring action force of the seals in the stiction region

Friction is a central phenomenon in most technical applications. The precise friction model is important for friction compensation in many control strategies. For a long time friction of various systems – among others for pneumatic systems – was described by Coulomb and viscous friction model added to Stribeck's term in the sliding regime. However these models in case of accurate positioning significant slow movements – especially zero velocity –were not appropriate. One of the first descriptions of this phenomenon, so called pre-sliding region is well known as Dahl's theory [8]. It proposed that the relationship between frictional force and position would be analogous to a stress-strain curve, completed with hysteresis like plastic deformation of materials [9].Since then, several models have been developed which are suitable for the description of slow movements. This article has not the task to compare different friction models, but to determine the limits of stiction regime in case of given pneumatic cylinder, and to discuss the effects of the mentioned factors.
The force-displacement characteristics of the rodless pneumatic cylinder OSP-P-210-032-700 were measured on chamber pressures from atmospheric pressure to overpressure of 6 bars. In addition the investigations of the rodless pneumatic cylinder were extended at horizontal cylinder arrangement on various load weights. The chambers p_A and p_B had the same pressure value, so the results do not influenced

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by pressure difference of the chambers. The measured results indicate the slope of the curves which depends only a little on the chamber pressure and on the load in the stiction area.
The width of the stiction area is obviously proportional to those, the exerted force can be maximal 15..20 N to stay within the stiction area. One of these trajectories shows Fig 4. The slope of the curve is about 40 N/mm. Due to parameter changes and measurement uncertainties a more precise calculation of the slope makes no sense.

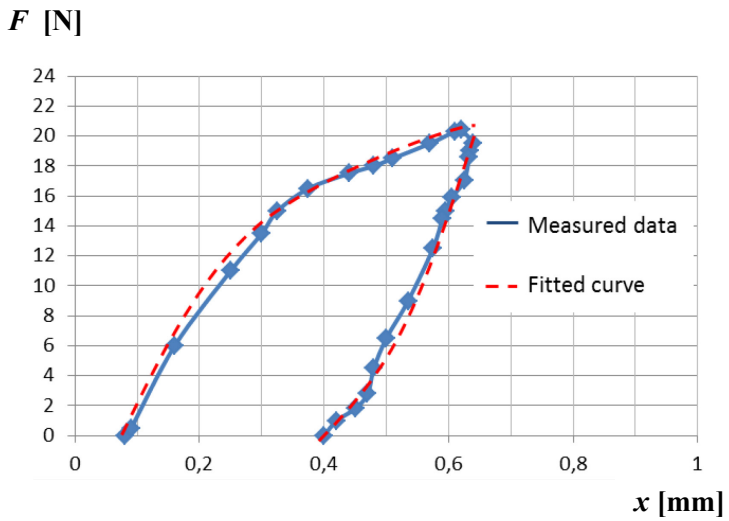

Figure 4. Force-displacement characteristics of cylinder OSP-P-210-032-700 at 6 bars chamber pressure

4. DISCUSSION

The investigated restoring action force of the seals is typically 20 N and causes a displacement of 0.5 mm magnitude in the stiction region. For greater forces the friction gets in the sliding friction regime, the piston gets to move continuously. The restoring force due to pressure change of the chambers – in case of piston displacement for the mentioned 0,5 mm - from (15) results a magnitude of 5 N in the middle of the stroke, which can be risen approximately until 20N at the end of it. It can be stated clear that the effect of the restoring action force due to chamber pressure change respect to the restoring force of the seals in the stiction region is marginal.

5. CONCLUSIONS

Double-acting pneumatic cylinders have two passive factors of resistance against external forces. For small displacements in the stiction region the restoring action force of the seals is dominant. The resilience of the pressure change prevails only for larger displacements, typically out of the stiction regime. The border of the two effects depends on the stiction limit, which is not clearly definable. It depends on the material, construction parameters and pretension of the seals, lubrication, stay duration of the piston, and the pressure rate of the action. During the measurements there was not any external guide equipped on the pneumatic actuator, which friction properties can influence the whole pneumatic cylinder.
The resilience of the cylinder against the acting forces should be examined in a different way for small and for large displacements. For small displacements (micrometre range) the stiffness of the pneumatic cylinder cannot be increased significantly with increasing of the chamber pressures. It can only be influenced by the design, and optimization of the seals and the guide.

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SMART MATERIALS TECHNOLOGY–BASED PRODUCTS APPLICATIONS IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The developments of new and innovative materials are contributing significantly to the large scale such as automotive industry. Century by century uncountable inventions and developments were dedicated to synchronized technological advancement. Smart materials are highly efficient materials and their performance comes at high costs associated with the high level of R&D involved. Therefore, invention of these materials conceptualized to produce effective sensors and actuators according to the purpose. Some everyday items are already incorporating such smart materials, and the number of applications for them is growing steadily. Invention of functional and intelligent materials introduced new concept of intelligent infrastructure systems, autonomous systems, smart structures and robotics in the bygone years. Smart materials include the piezoelectric materials (PZT).

Keywords: automotive industry; innovative technologies; sensors; smart materials; Lead Zirconate Titanates (PZT);

1. INTRODUCTION

Can we imagine “the innovative society” without “the innovative materials” or without their applications? In several industries, including in the automotive industry, the smart and innovative materials will change the look and feel of the cars and they can provide significant benefits when they are used to replace conventional devices by reducing vehicle mass, component size and complexity, and improving design flexibility, functionality and reliability [12,24].
Historically development and advancement of societies have been intimately related to materials and its development. With time, techniques were discovered for producing materials that had properties superior to naturally occurring materials. The development of many technologies that make our life comfortable is closely related to materials [1].
This new century is dedicated to development of materials and development of intelligent infrastructure systems. Accomplishment of this goal necessitates better understanding of available technologies, physical theories, mathematical theories, experimental investigations, solid mechanics and mechanics of materials at various scales, development in materials science and in various other scientific concepts. This historical achievement can be ensured by devoted individuals and synchronized assembly of interdisciplinary researchers. Now, it is a new era of development [2,4,5,20-27]. Even development of new material can open new perspective in these relevant problems. Several small smart structures use actuators and sensors at milli– and micro–scales to achieve a certain goal (active and passive control). Nowadays, there are numerous research activities at universities, companies, and government organizations worldwide. Researchers are constantly finding combinations of technologies to increase avenues for commercialization.
Materials technology created products and components that are smaller, smarter, multifunctional, environmentally compatible, more survivable and customizable. These products will not only contribute to the growing industrial revolutions but will have additional effects on manufacturing logistics and personal lifestyles. Variety of materials known as advanced materials has been developed for different applications [12,16,17,20-27].
To achieve a specific objective for a particular function or application, a new material or alloy has to satisfy specific qualifications related to the following properties [12,22,24]:

- technical properties, including mechanical characteristics such as plastic flow, fatigue and yield strength and behavioral characteristics such as damage tolerance and electrical, heat and fire resistance;

- technological properties, encompassing manufacturing, forming, welding abilities, thermal processing, waste level, workability, automation and repair capacities;
- economic criteria, related to raw material and production costs, supply expenses and availability;
- environmental characteristics, including features such as toxicity and pollution; and
- sustainable development criteria, implying reuse and recycling capacities.

If the functions of sensing and actuation are added to the list, then the new material/alloy is considered a smart material.

As humanity has made great progress in processing elementary materials, they have become milestones that marked the early stages of mankind development. It was only the beginning of the recent hundred years that materials became multifunctional and required the optimization of different properties. With the last evolution, the concept has been driving toward composite materials where two or more distinct material phases are being combined together to provide a better combination of properties. Currently, the next evolutionary step is being contemplated with the concept of smart materials [2,7,8,12,16,21,24-27].

Science and technology have made amazing developments in the design of electronics and machinery using standard materials, which do not have particularly special properties (i.e. steel, aluminum, gold). Imagine the range of possibilities, which exist for special materials that have properties scientists can manipulate [7,8,17]. Some such materials have the ability to change shape or size simply by adding a little bit of heat, or to change from a liquid to a solid almost instantly when near a magnet. These materials are called smart materials.

Smart materials, similar to living beings, have the ability to perform both sensing and actuating functions and are capable of adapting to changes in the environment. In otherwords, smart materials can change themselves in response to an outside stimulus or respond to the stimulus by producing a signal of some sort. By utilizing these materials, a complicated part in a system consisting of individual structural, sensing, and actuating components can now exist in a single component, thereby reducing overall size and complexity of the system.

2. INNOVATIVE MATERIALS FOR THE AUTOMOTIVE INDUSTRY

The key to 21st century competitive advantage will be the development of products with increasing levels of functionality. “Smart Materials” will play a critical role in this development, where we define these as materials that form part of a smart structural system that has the capability to sense its environment and the effects thereof and, if truly smart, to respond to that external stimulus via an active control mechanism. Due to their high flexibility, versatility and power–to–weight ratio compared with traditional rigid actuators, the smart materials have the potential to be a highly disruptive emerging technology (as distinguished from a conventional technology), as a field of technology that broaches new territory in some significant way, with new technological developments [2,16,21,25].

Smart materials are nowadays being used in all spheres of human life and technology. A lot of research is going on to utilize their potential in various engineering applications which may prove useful for us. A wide variety of smart materials exist, which includes piezoelectric materials, shape memory alloys, etc. One of the foremost challenges in robotics is the development of muscle–like actuators that have the capability to reproduce the smooth motions.[3] The criteria for artificial muscle technologies that allow for specification of new actuator technologies include stress, strain, strain rate, cycle life, and elastic modulus. Thermal actuator–based artificial muscles offer heat resistance, impact resistance, low density, high fatigue strength, and large force generation during shape changes. Artificial muscle technologies have wide potential applications in industrial smart structures as actuators, in robotics, aerospace, automotive industry, medicine, noise control etc. [3] Over the past several decades the Micro–Electro–Mechanical Systems (MEMS) researchers and developers have demonstrated an extremely large number of micro–sensors for almost every possible sensing modality including temperature, pressure, inertial forces, chemical species, magnetic fields, radiation, etc. Surprisingly, even though these micro–actuators are extremely small, they frequently can cause effects at the macro–scale level. New artificial muscles are

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enabling diverse technologies. The broad impact of new artificial muscles is potentially analogous to the impact of piezoelectric materials on the global society.

Piezoelectric actuators are also extremely good in positioning applications and are commonly used as sensors and actuators in Micro–Electro–Mechanical Systems (MEMS) devices because of their high sensitivity. While the functional elements are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the micro–sensors and micro–actuators. The most common applications of this type of material are in actuators and sensors. The majority of historic actuators are made of ceramic piezoelectric materials. One of the most common applications is in the field of robotics in the development of artificial muscles [9,13,15,18,19].

Smart materials are used in number of areas. The potential future benefits of smart materials, structures and systems are amazing in their scope. This technology gives promise of optimum responses to highly complex problem areas by, for example, providing early warning of the problems or adapting the response to cope with unforeseen conditions, thus enhancing the survivability of the system and improving its life cycle. Moreover, enhancements to many products could provide better control by minimizing distortion and increasing precision [7,20,22,24].

Smart materials are being used in the automotive industry already. Automakers are already using sensors and actuators made of smart materials to replace existing motors and mechanical devices used for purposes like adjusting mirrors, seats and headrests, or operating door locks and windows, or to release latches and etcetera.

Several devices are used, for example, for the deployment of air bags and anti–lock braking systems (ABS). In the modern cars are identified over 40 other automotive sensor applications, some of which could be addressed by the use of smart materials [2,8,12,15].

Some smart materials are being used in automatic light and heat control in the automotive industry (e.g. self–dimming mirrors and rear windows). A less mature application is the use of actuators as substitutes for small motors, the advantages here being reduced weight and fewer failures because of reduced complexity. Also less mature is the use of smart materials to reduce noise and vibration, resulting in enhanced comfort and safety benefits, especially for professional drivers.[2,4,24]

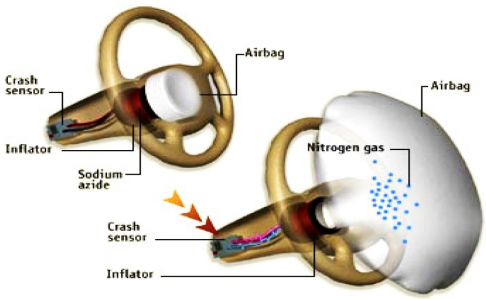

Figure 1. Example of sensor applications in air bagstechnology

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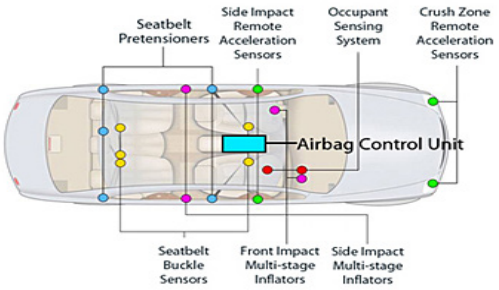

Figure 2. Example of sensor applications in anti–lock braking systems (ABS)

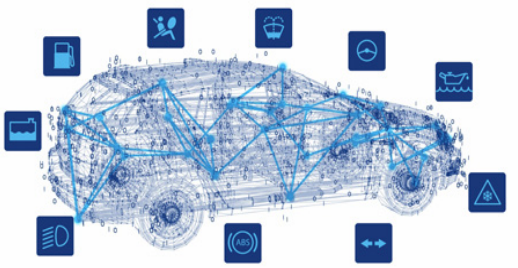

Figure 3. Automotive sensor applications

To replace conventional systems or introduce new capabilities into automobiles, systems based on smart materials and structures technology need to add functionality, performance and adaptability without decreasing reliability, while marginally increasing cost and weight.
Automotive applications tend to require high volume and high performance, the ability to function in a hostile environment and a low cost. Smart materials are likely to succeed in this sector if they can perform more than one function or if they can be integrated in a way that reduces assembly and production costs.
However, to advantageously exploit the capabilities of smart material–based sensors and actuators in vehicle technology requires multidisciplinary approaches to design and optimization, where improved controllability, maintainability and extendibility are key goals.
The innovative applications of smart materials in the automotive engineering includes but are not limited to [6, 24]:

- Smart material process and mechanism studies for automotive applications;
- Advanced vehicle control and multidisciplinary modeling to support the design of novel smart materials–based automotive components and/or systems;
- New designs and analyses of smart materials–based automotive components and/or systems for improving automotive performance, for example in reliability, safety, robustness and extendibility;
- Position/vibration/shock control of vehicles with smart materials–based components to improve driving comfort, handling stability and crashworthiness;
- Field testing and evaluation of practical automotive application systems featuring smart materials.

From an innovative materials engineering perspective, a passenger car is an aggregation of various control systems that interact with each other in complex ways. Each control system is made up of a plant, sensors, actuators and an electronic control unit (ECU), with many circuits which include passive components (such as resistors, capacitors, inductors) and integrated circuits (such as microcontrollers, communication gadgets). Some examples of automotive ECUs include:

- engine – controls engine performance and emissions;

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- transmission – controls automatic transmission;
- electronic stability control – controls braking system;
- chassis – supports ride control system;
- instrument cluster – provides information to the driver;
- heating, ventilation, and air conditioning (HVAC) – controls climate inside the cabin;

Smart materials provide a choice to engineers because they offer new opportunities to reduce product complexity and weight of a car or automotive. Actuators and sensors made from smart materials also have the ability to improve vehicle performance and fuel economy, as well as enhancing convenience features [2,8,13,20,24].

Smart materials are materials that react to changes in the environment and consistently repeat recurring behavior. In the automotive sector, there have been some recent breakthroughs in using shape–memory alloys and piezo–ceramic materials which have numerous application opportunities [2,8,13].

Most of smart materials used in the automotive industry change their shape or structural properties on external stimuli like heat, magnetic field, electrical voltage or stress. The most preferred smart materials, like shape–alloy metals can "remember" their shapes and structures and revert to their original states once the external stimuli is removed [8,13,24,25].

The introduction of smart materials technology–based products consolidated the developments in the automotive sector. Important technical issues included enhanced actuator performance, device integration and cost–reduction [2,20,24,25].

Although the concept of Integrated Vehicle Management and its associated technologies can be complex in its implementation, it is essentially based upon a simple idea: the more you know about a particular machine's ability to function, the quicker you can act to prevent malfunctioning. This rapidly developing area of engineering seeks to enable better management of both the vehicle and vehicle fleet health. Use of this concept can improve vehicle reliability, safety, and reduce unnecessary, unscheduled maintenance through the use of diagnostic and prognosis systems that monitor data and overall vehicle health [10,11,20,24,25].

As a result, the smart materials are used in several functional applications in the automotive industry [2,24,25]:

- passive sensors, for converting mechanical force or movement into an electrical signal, such as accelerometers, knock sensors, suspension load sensors, airbag impact sensors and intruder alarms etc.
- actuators, for converting electrical energy into mechanical displacement, such as valves for fuel injection systems, and devices for positioning headlamps and mirrors.

Automobile manufacturers and their components suppliers are working with the material scientists and applications engineers to develop new uses of smart materials to further enhance automobile safety, performance, energy–efficiency and comfort. The automotive industry continually implements technological innovations that make cars smarter, and therefore the smart sensors and actuators will play an increasingly important role, as the critical input/output devices for many automotive electronic systems.

Sensors are the key to life and survival – and to the success of modern technology. Nature has provided living creatures with a wealth of sensors for a light, sound, temperature, speed, motion, distance, force, pressure, acceleration, odor and so on – sensors, whose performance and specifications have often not been matched yet by man–made devices. Even at today's high level of electronics and information technology, sensors remain the crucial and decisive interface needed to reliably relate phenomena occurring in the environment to corresponding electric signals that can be processed to obtain the desired information and subsequent correct reaction of systems [9].

3. PIEZOELECTRIC CERAMIC COMPONENTS

Smart materials have one or more properties that can be dramatically altered, for example, viscosity, volume, conductivity. The property that can be altered influences the application of the smart material [9,18,19,24,25].

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Smart materials include the piezoelectric materials. Some everyday items are already incorporating smart materials, and the number of applications for them is growing steadily.
Lead zirconate titanate ($Pb[Zr_xTi_{1-x}]O_3$) – more commonly known as PZT, is the most common piezoelectric ceramic in use today. Currently, industrial and manufacturing is the largest application market for piezoelectric devices, followed by the automotive industry.
Many engineers are still learning about the piezoelectric effect or have little exposure to ceramic material advances. But when they're combined, ceramics and piezoelectric elements can lead to incredible improvements in component design and function.
When a piezoelectric material is deformed, it gives off a small electrical discharge. When an electric current is passed through it, it increases in size (up to a 4% change in volume). They are widely used as sensors in different environments. The piezoelectric effect describes the relation between a mechanical stress and an electrical voltage in solids. It is reversible: an applied mechanical stress will generate a voltage and an applied voltage will change the shape of the solid by a small amount. In physics, the piezoelectric effect can be described as the link between electrostatics and mechanics [9,18,19,24].
Piezoelectric ceramic components composed of PZT have enabled many recent technological innovations in the automobile industry. The PZT components can be found throughout many state–of–the–art vehicles, enhancing safety, performance, energy–efficiency and comfort.

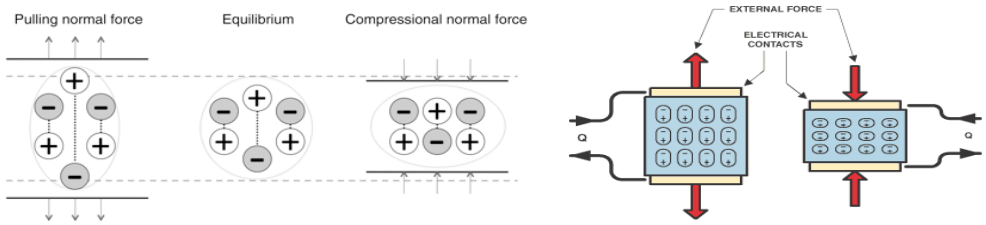

Figure 4. The piezoelectric concept and the piezoelectric effect

Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance, process control and for research and development in many industries. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built–in miniature piezoelectric sensor.
PZT's attributes of producing an electrical charge when mechanically compressed or vibrating when an electrical charge is applied, make it very conducive for passive sensing, active transmitting and mechanical displacement applications. Piezoelectric materials are particularly useful for sensing applications due to its high sensitivity and permittivity. As such these piezoelectric ceramics are frequently used in low power applications as transducers, receivers and generators.

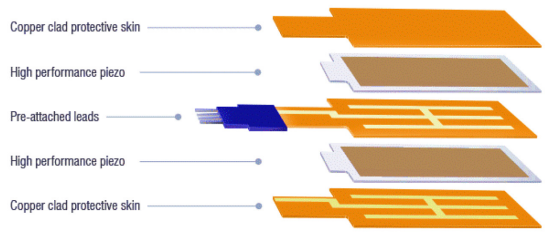

Figure 5. Piezoelectric sensors

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The automotive industry utilizes different types of piezoelectric materials, each providing a set of unique properties suitable for a range of applications. The piezoelectric materials are a machineable ceramics and can be precision dimensioned into tubes, rings, discs, plates, and hemispheres, tailored to exacting customer specifications. The PZT material is also versatile from a forming aspect as it can be net shaped by pressing, extruding and casting into these same shapes as well as complex components including the multilayer actuators. Sizes range from microns to centimeters. Electrode choices are extensive including Silver, Nickel, vacuum deposited Nickel–Chrome, Gold, Tin, Aluminum and Vanadium [9,12,17–19].
Piezo–ceramic actuator and sensor design is based on customer specifications which generally include:

- the motion requirement (for actuators) or the voltage requirement (for sensors);
- the force requirement (for actuators) or the current requirement (for sensors);
- the response time;
- the operating frequency range;
- the space available for actuator;
- the voltage available;
- the stability;
- the temperature range.

The piezoelectric ceramic materials used for sensors (such as PZT ceramic) have a piezoelectric constant/sensitivity that is roughly two orders of magnitude higher than those of the natural single crystal materials and can be produced by inexpensive sintering processes. The piezo–effect in piezo–ceramics is „trained", so their high sensitivity degrades over time. This degradation is highly correlated with increased temperature. Typical PZT characteristics include:

- wide range of frequencies in transmit and receive (sub–audible, audible, ultrasonic);
- high output, low drive material;
- high frequency, fast response time;
- high sensitivity for active or passive use;
- ability to use with low or high voltage drive circuits;
- good mechanical and acoustic coupling;
- wide variety of shapes and sizes that can be customized to meet specific requirements and applications;
- wide variety of compositions that can be selected to meet specific requirements and applications.

PZT–based materials are components of ultrasound transducers and other sensors and actuators, as well as high–value ceramic. PZT is also used in the manufacture of ceramic resonators for reference timing in electronic circuitry. Therefore, piezoelectric sensors are destined to:

- vibration, shock and acceleration measurements;
- acoustic measurements;
- pressure measurements;
- force and load measurements;
- torque measurements;
- other general topics;

These small and strong materials offer a wide frequency range, suiting a variety of applications and specific design needs without sacrificing performance. Typical PZT applications include the automotive industry, such as power seat controls, reversing/collision avoidance sensors, anti–knock sensors, intrusion alarms, vibration monitoring, flow and level sensors, computer hard drives, touchscreen displays, advanced acoustics and optical switching etc. For example, we will find PZT sensors under the hood detecting engine knocking, PZT transducers in the gas tank measuring the fuel level, PZT actuators operating valves in pneumatically adjustable driver's seats, PZT ultrasonic transducers on the front, rear, and side of the car as parking sensors, and PZT generators in the wheels harvesting energy that powers tire pressure monitoring systems.

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4. CONCLUSIONS

By definition, smart materials and smart structures – and by extension smart systems – consist of systems with sensors and actuators that are either embedded in or attached to the system to form an integral part of it. Smart materials are used in number of areas. The potential future benefits of smart materials, structures and systems are amazing in their scope. This technology gives promise of optimum responses to highly complex problem areas in the automotive industry, enhancing the survivability of the system and improving its life cycle. Moreover, enhancements to several products could provide better control by increasing the precision. Another possible benefit is enhanced preventative maintenance of systems and thus better performance of their functions.
One of the first attempts to use the smart materials technology involved materials constructed to do the work of electromechanical devices. Since then, many types of sensors and actuators have been developed to measure or excite a system. This technology is still in its infancy and the scientific community is just beginning to scratch the surface of its potential. It has been emphasized that materials especially the advanced materials are scientifically and technologically very important for the development of the automotive sectors.
By combining our active and passive technology with the innovative electronics and sensing capabilities, intelligent systems are created which help enhance the safety of pedestrians, drivers and passengers. The integrated technology warns the driver, actively assists to help avoid danger and intervenes to lessen the impact of an accident or helps to avoid one altogether. This integration is also key to the future of enhanced vehicle control, car–to–car, car–to–infrastructure and occupant/pedestrian protection developments.
Analyzing and reacting to the many sensor data inputs available on a vehicle's electronic communication network leads to systems that use active safety data to help ready passengers before a crash occurs and better mitigate the effects of the crash through active seat belt systems or pre–arming airbags. Using proprietary algorithms, these intelligent systems sense, calculate and adapt to help drivers avoid or mitigate an accident. Incorporating this advanced awareness yields a higher level of safety, efficiency, comfort and convenience.

5. ACKNOWLEDGMENT

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SUSTAINABLE MANAGEMENT OF BIOMASS ENERGY IN RURAL AND URBAN CONTEXT

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ABSTRACT

The most sustainable energy is the energy not used. Best way to (not) use energy is the proper design of a facility or an energy consuming system. The remaining energy needs have to be covered with energy utilisation of waste materials, renewable energy sources and, until the previous solutions are not sufficient to satisfy the energy demands, the last is the use of conventional fossil and nuclear energy sources. In terms of renewable energy, biomass has an important role today. However, there is a difference between available inputs and utilisation when considering biomass energy possibilities in rural and urban context. This paper suggests biomass energy possibilities that are recommendable in rural context: possibilities of solid biomass combustion, of liquid biofuels and of anaerobe digestion. Also important are possibilities of solid biomass combustion and wet biomass digestion for urban energy production, although with some remarks on system considerations of urban biomass. Most advanced solutions for sustainable management of biomass energy include circular systems, both in rural and urban context, as recommended

Keywords: biomass, energy, sustainable, urban, rural, circular economy

1. INTRODUCTION

Energy not used is the cheapest energy is – this attitude can serve as the basis for planning a sustainable energy supply of a region, production facility or consumer [4]. The energetic planning and its implementation are very important in case of a facility, which is supported also by EU and domestic regulation [14]. This is closely followed by energy utilisation of waste materials [5]. Then, the use of renewable energy sources follows, to the sustainable extent. The last is the use of conventional fossil and nuclear energy sources, until their replacement is solved in ab economically efficient and sustainable way.
This paper aims to suggest possibilities for sustainable biomass energy production in rural and urban areas. By using biomass and wastes, and through the technologies of circular economy, energetic self-sufficiency is reachable [10].

2. MATERIALS AND METHODS

The methodology used in the elaboration of this paper was to collect, process and suggest possibilities on the sustainable management of biomass energy, both in rural and urban areas. Materials used are the publications listed among the references used in this paper.

3. RESULTS AND DISCUSSION

3.1. Biomass energy in rural context

Possibilities of solid biomass combustion for rural energy production

A small biomass-based CHP with ca. 2 MW electric output (and with ca. 4 MW thermal output) can be applied to cover the heat demand of a small settlement or a settlement centre (Fig. 1), at the same time producing electricity, which is universally (grid) marketable.

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Figure 1. A 2 MW wood-chips power plant in Güssing, Austria (ca. 3000 inhabitants) [6]

According to our calculations [6], with ca. 1.2 billion HUF investment this type of a wood chips based power plant can be established within 2 years, paired with a discounted payback period (DPP) of 5.6 years in case of at least 80% heat utilization and no financial support, and with 1.2 years in case of an additional 50% investment support. The employment increase amounts to 350 people including the 20 people serving the power plant. The energy plantations need 1400 ha area.

Possibilities of liquid biofuels for rural energy production

Biofuels are made from rural biomass. A good example is ethanol, nowadays mainly produced out of corn in Hungary. The main capacities are owned by Hungrana Ltd., which is processing around one tenth of the yearly domestic corn production (Fig. 2).

Figure 2. Hungrana facilities producing ethanol [7]

Hungarana Ltd. is one of the largest maize processors in Europe. The facility processes corn into corn starch and isoglucose for the food processing industry as well as bioethanol for the petrochemical industry. The company is proud to be a bioeconomy company, that is, to make natural products exclusively by

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natural means, using a broad range of the most modern technologies and renewable energies, without waste. Because of the changes in the sugar market and the growing demand for biofuels, the company has tripled its bioethanol production capacity in an expansion project completed in July 2008. Today the plant produces around 150,000 t of bioethanol per year, by processing over one million tonnes of corn [7].

Possibilities of anaerobe digestion for rural energy production

In our former investigations [3], six models with different sizes were examined for heat production and cogeneration. Among these, models 1-5th were based on an input mixture of two-third pig and cattle manure and one-third silage, with 16% dry matter content. The 6th model is based on approx. 50% liquid manure, one-third manure with litter, and the rest made up mainly of corn silage, with 15% dry matter. The 1st and 3rd models are based on actual German plants' data, the 2nd, 4th and 5th on average of German plants' data, whereas the 6th model on the data of one of our newest reference plant. The latter model uses two-phase (mesophilic + thermophilic) digestion, while the smaller plants use one-phase mesophilic technology. The small plants (1st , 2nd model) use Diesel engines with fuel injection, the electric efficacy of which is 4-5% lesser than that of the Otto-engines used at the larger plants (3rd-6th models); moreover, their diesel oil demand is also considerable. The key operational and economic base data of the models investigated are described in Tab. 1. The very good values of model 3 are perhaps describing the achievable optimum (proper mixture, proper sizing).

Table 1. Biogas Plant Models for Heat Generation and Cogeneration [3]

Model	***1***	***2***	**3**	**4**	***5***	***6***
Input, t/year	*3 182*	*4952*	17 411	23968	*47936*	*90255*
Volume of Digester, gross m^3	*420*	*750*	2 400	3000	*5500*	*8000*
CHP, kW$_{el}$	***55***	***100***	**330**	**500**	***1000***	***1672***
Bio-manure Storage, m^3	*410*	*410*	1700	2770	*2770*	*2770*
Temperature of Digestion	mesophilic					*M+T**
Investment costs, M HUF	*61*	*137*	191	495	*908*	*1400*

In the different size categories, biogas investment can be facilitated economically even under present macro-economic conditions, though using different technological solutions. In small-sized plants, heat energy utilization is to be considered (preferably to cover own demands), because of the lesser electric efficacy and extra material costs, and extra investment costs of cogeneration. This can be an alternative to natural gas firing even under present price conditions, especially when the biogas investment is weighed strategically, together with its complex (environmental, employment-assuring) benefits. In middle sized and large plants the own consumption is not realizable because of the greater quantity, therefore, cogeneration production of electricity is advised, under partial or full heat utilization (Fig. 2). Under worsening Hungarian conditions of "green" electricity take-over, the transformation of biogas to another marketable product, bio-methane, is to be considered. This involves no waste-heat generation, the utilization of which is always a critical point of operating cogeneration. Based on waste materials, or, perhaps, also with utilization of the carbon-dioxide from purification, in large plant sizes this can mean a profitable way of green energy production

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3.2. Biomass energy in urban context

Biomass from urban spaces, as compared to rural biomass, consists mainly of municipal and industrial wastes and wastewater, and to a smaller extent, of biomass residues from maintenance of green areas.

Possibilities of solid biomass combustion for urban energy production

As regards the energy use of the constantly re-generated municipal solid waste and its considerable biomass (carbon) share, waste incineration plants can provide a solution. As a study highlights, waste utilization and waste prevention should contradict each other [15]. Countries that have high waste incineration rates also achieve the highest recycling rates, e.g. the Netherlands, Switzerland, Austria, Germany and the Scandinavian countries. Common base feature of their policies is that they have sharply restricted or even banned landfill as a cheap disposal route, for example by taxes, or prohibiting legislation. Whereas waste reduction is a matter of material efficiency of manufacturing and of altering of consumer behaviour favouring products including less waste within their life cycle, waste incineration remains an important tool for disposal security and energy recovery in a recycling economy based on material and resource efficiency.
Linköping has an existing waste incineration plant (Fig. 3) with a capacity of 250,000 tonnes of waste a year and is investing in order to increase the capacity to 350,000 tonnes of waste a year. The base supplier of heat is the waste incineration plant with a total capacity of 70 MW and an additional 10 MW from flue gas condensing. Electricity can also be produced by a steam turbine integrated with an oil-fired gas turbine, a so-called hybrid system. The hybrid system has a capacity of 47 MW_{el} [7].

Figure 3. The now 80 MW capacity Linköping waste incineration plant [11]

Possibilities of wet biomass digestion for urban energy production

Wastewaters and easily biodegradable food residues as well as green plant material (e. g. grass clippings) can be used as substrate for anaerobe digestion. When converted into biogas production, these can serve even as vehicle fuel. A former study investigating the local possibilities of biogas as fuel for public transport has evaluated the local sources of biogas, the sewage treatment plant and the landfill gas from the waste disposal site with the result that both are principally good for vehicle fuel (although used for other purposes). The advantages and disadvantages of biogas from different sources were summarized in the

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Tab. 2 from [1]. An example of biogas production can be the biogas plant in Linköping, using organic food wastes from the town and also additives from neighbouring agricultural producers (Fig. 4.).

Table 2. Biogas Plant Models for Heat Generation and Cogeneration [1]

Biogas possibilities	**Sewage plant**		**Firm waste disposal site**	
	Advantage	**Disadvantage**	**Advantage**	**Disadvantage**
Amount	2,2 M m^3			0,7 M m^3
Quality	60-65 % CH_4	360 mg S / m^3	1-2 ppm H_2S	45-48 % CH_4
Remark	Available locally	Used for own electricity supply	Available locally. Surplus at low price.	Ownership of utilization rights.

Figure 4. Biogas plant in Linköping, based mainly on municipal wet organic wastes [17]

Urban biomass as energy source: system considerations

Of course, distinction should be made in terms of nature and quantity of waste generated in case of the utilization of urban waste, as well. Family housing areas of the cities produce bio-waste that is less dangerous to the environment than the wastes of processing industry or slurry from large-scale animal husbandry, remarkably because wastes are generated not at a single point, in large amounts, but rather scattered in space. A study using GIS methods confirms [11] that compost use of detached houses' organic wastes may be recommended, involving less cost than small-scale, household-sized biogas production. The power management of the settlement is helped by this solution by the lesser quantities of waste to be removed, so that transport energy demand used in waste logistics will be smaller.

3.3. Sustainable management of biomass energy in rural and urban context

A sustainable, farm-scale closed-circuit biomass energy system for rural areas

Combining pathways of bioenergy production can lead to closed cycle material flow, as in the example of a combined ethanol and biogas production system elaborated by [9] (Fig. 5.). Within this system, the distillation residue of alcohol production serves as an additive for biogas production. In turn, the surplus heat of biogas-based co-generation can supply the heat demands of alcohol production. The digested manure and alcohol fermentation residues can be used for enhancing soil fertility for biomass production, while the produced electric power together with surplus heat can be commercialized.

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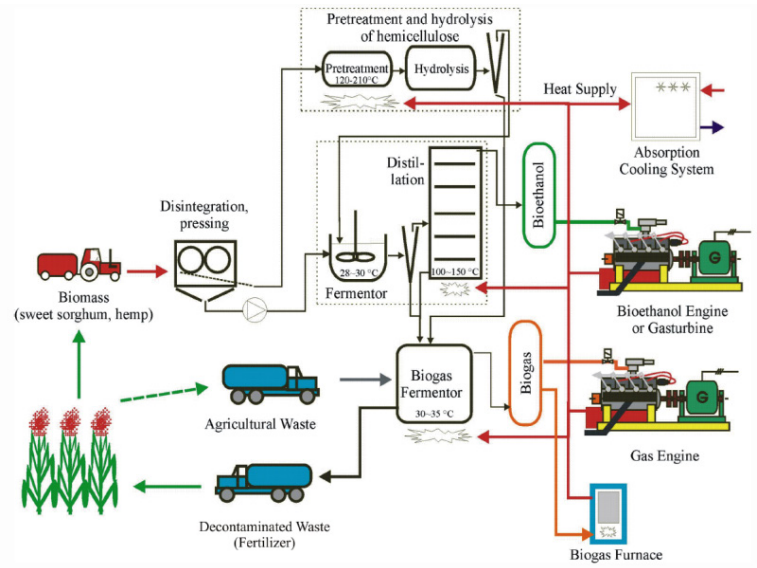

Figure 5. Example of a combined ethanol and biogas production system [9]

Complex circular systems at large - the Östergötland case: a biomass-based complex regional ecosystem including urban areas

After considering a farm-scale closed-circuit system, it is useful to consider an already established large-scale case of circular economy, that of the Östergötland region in the southern part of Sweden.
First, a commonly accepted (Wikipedia) definition for circular economy should be cited here:
"The circular economy is a generic term for an industrial economy that is, by design or intention, restorative and in which materials flows are of two types, biological nutrients, designed to re-enter the biosphere safely, and technical nutrients, which are designed to circulate at high quality without entering the biosphere." [16]
This definition focuses on biomass and its constituents as "biological nutrients" – however, on the energy side, these are coupled with usage forms of biomass energy. The system of the "circular economy", as shown on Fig. 6, consists of more than 100 environmental technology companies, managed by a system operator company, which is a joint venture of these companies overseen by the involved communities and the local university. Managing, maintaining and developing such a large technical system is a real challenge towards sustainable management of locally available biomass resources [12].
The energy supply of the cities Linköping and Norrköping is based on Waste to Energy solutions that are based on local biomass. The combined heat and power plants (waste-incinerating plants) utilize the waste of these cities, tri-generating energy for these cities in the form of district heating, district cooling, and electricity. Other utilizers of urban biomass are wastewater treatment plants, using communal and industrial wastewater and thus producing biogas for tri-generation in biogas plants and as vehicle fuel into the biogas distribution net. Other biomass energy solutions in the system are the ethanol and biodiesel production facilities. These material and energy flows are based on the local agricultural sector: agriculture provides the crops and livestock for the local food industry and through the restaurants the waste oil for biodiesel production, and the grain for the ethanol plant. As a closing (or starting) point in the circle, agriculture also takes up the end-products of the processes as livestock feed and biofertilizer.

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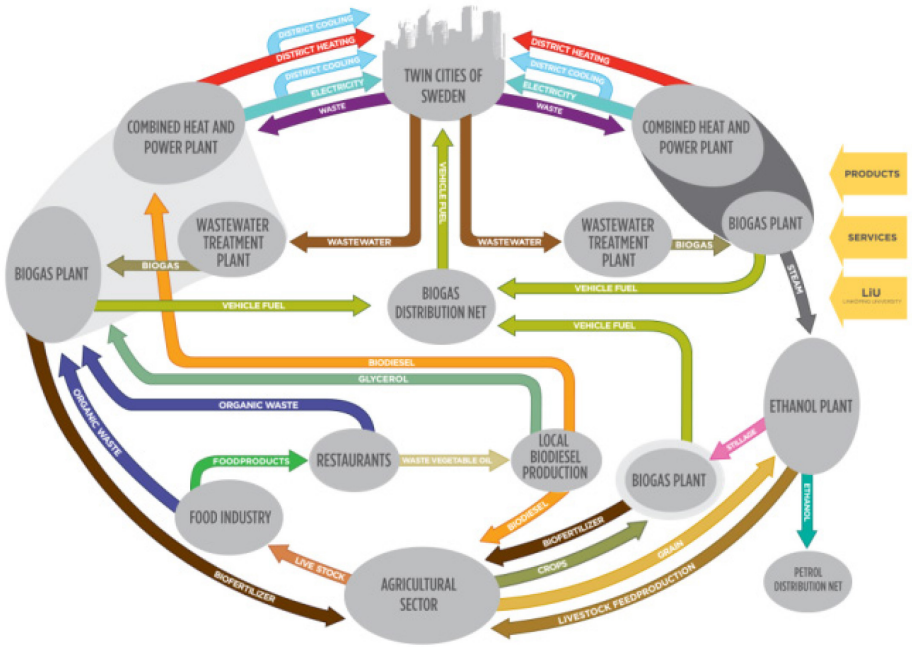

Figure 6. Circular economy in Östergötland, Sweden [1]

An investigation of the system says that "the strong link between the industry, government and academia with respect to innovative approaches for applying renewable energy and industrial symbiosis plays a strong role at the macro level in the Östergötland community" [1].

4. CONCLUSIONS

Considering the possibilities of both rural and urban areas in bioenergy production, the conclusion can be drawn that bioenergy has a firm place among sustainable solutions for energy supply, supported with proper management.

The adequate way of biomass energy production is decentralised energy supply, as this is the optimum use of combined heat and power generation from both solid and wet biomass. In rural context, heat can be used to power production facilities, or supply the needs of smaller settlements. In urban context, municipal solid wastes and wastewater can serve as the basis for cogeneration (trigeneration).

As regards liquid biofuel production, ethanol is produced from rural resources, that is, corn produced on arable land. This is better conducted in a system that also includes other bioenergy routes as well, as in case of a combined ethanol and biogas production system. This provides a closed-circuit material management, at the same time producing renewable energy in a sustainable way.

Perhaps the most complex and more promising example of possible biomass energy solutions is the case considered in the regional biomass-utilization and waste management system of Östergötland. This covers both urban and rural solutions, connecting them to a network of technologies serving sustainable material- and energy management.

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THE NON-INTERACTING MAGNETIZATION FORMULA FROM THE PENDULUM MOTION OF DIPOLES

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ABSTRACT

Non-interacting magnetization Taylor expansions are calculated in 2D and 3D at high external field according to the vibrational model. In this approach all dipoles are moved as a linear pendulum independent from each other. The temperature is taken into account according to the equipartition theorem, thus all particles have the same kinetic energy: $k_BT/2$ in 2D and k_BT in 3D. The expansions valid only at high external magnetic field due to the linearisation of initial differential equation. On the second part of this paper the Maxwell-Boltzmann distribution is taken into account to determine the probability density function of the angular velocity. The ratio of the particles which has zero angular velocity in 2D is the maximum, in 3D is zero. Therefore the theoretical prediction is in better agreement with the exact formula of magnetization in 2D than in 3D. In this approach the effect of negative magnetization is able to come into existence in the non-interacting fluidum.

Keywords: Langevin function, vibrational model, non-interacting magnetization, linear pendulum, 2D and 3D magnetization, negative magnetization

1. INTRODUCTION

1.1. The Taylor expansions of initial magnetization

The simplest magnetization formula ignores the influence of dipolar interaction between dipolar particles, take into account only the applied external magnetic field. In this case according to the Boltzmann distribution the average of the cosine value of angle between external field and the dipole is:

$$\langle \cos\varphi \rangle = \frac{\int \cos\varphi \ \ exp(a\cos\varphi) d\Omega}{\int exp(a\cos\varphi) d\Omega}, \tag{1}$$

where φ is the angle between H external field and m strength dipole moment, $a = mH/k_BT$, and Ω denotes the orientation (k_B: Boltzmann factor, T: temperature). The phrase „non-interacting" means the independent magnetization divided by saturated magnetization. In 3D this expression leads to the Langevin function [1]:

$$\langle \cos\varphi \rangle_{3D} = \mathcal{L}(a) = \coth a - 1/a. \tag{2}$$

In 2D the (1) can be written by dividing two Bessel functions [2]:

$$\langle \cos\varphi \rangle_{2D} = I_1(a)/I_0(a), \tag{3}$$

where I_1 is the modified Bessel function of the first kind of first order and I_0 is the modified Bessel function of the first kind of zero order. Performing the Taylor expansion of exponential function in the numerator and denominator of (1) centered at zero and executing the integrals (or performing the expansion of Bessel functions in case of 2D) the well-known expressions of the non-interacting magnetization can be written as:

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$$\langle\cos\varphi\rangle_{2D}^{H\to 0}=\frac{\frac{1}{2}a+\frac{1}{16}a^3+\frac{1}{384}a^5+\frac{1}{18432}a^7+\frac{1}{1474560}a^9+\cdots}{1+\frac{1}{4}a^2+\frac{1}{64}a^4+\frac{1}{2304}a^6+\frac{1}{147456}a^8+\cdots}=\frac{1}{2}a-\frac{1}{16}a^3+\frac{1}{96}a^5-\frac{11}{6144}a^7+\frac{19}{61440}a^9-\cdots, \tag{4}$$

$$\langle\cos\varphi\rangle_{3D}^{H\to 0}=\frac{\frac{1}{1.5}a+\frac{1}{15}a^3+\frac{1}{420}a^5+\frac{1}{22680}a^7+\frac{1}{1995840}a^9+\cdots}{\frac{1}{0.5}+\frac{1}{3}a^2+\frac{1}{60}a^4+\frac{1}{2520}a^6+\frac{1}{181440}a^8+\cdots}=\frac{1}{3}a-\frac{1}{45}a^3+\frac{2}{945}a^5-\frac{1}{4725}a^7+\frac{2}{93555}a^9-\cdots. \tag{5}$$

These expressions are rewritable into iterational formula:

$$\langle\cos\varphi\rangle_{2D}^{H\to 0}=\frac{\sum_{n=0}^{\infty}\frac{a^{2n+1}}{X_n}}{\sum_{n=0}^{\infty}\frac{a^{2n}}{Y_n}},\ \text{where}\ \begin{matrix}X_0=2\\Y_0=1\end{matrix},\ \text{and}\ \begin{matrix}X_n=X_{n-1}(4n^2+4n)\\Y_n=Y_{n-1}(4n^2)\end{matrix}, \tag{6}$$

$$\langle\cos\varphi\rangle_{3D}^{H\to 0}=\frac{\sum_{n=0}^{\infty}\frac{a^{2n+1}}{X_n}}{\sum_{n=0}^{\infty}\frac{a^{2n}}{Y_n}},\ \text{where}\ \begin{matrix}X_0=1.5\\Y_0=0.5\end{matrix},\ \text{and}\ \begin{matrix}X_n=X_{n-1}(4n^2+6n)\\Y_n=Y_{n-1}(4n^2+2n)\end{matrix}, \tag{7}$$

moreover dividing by Taylor expansions:

$$\langle\cos\varphi\rangle_{2D}^{H\to 0}=\frac{\sum_{n=0}^{\infty}\frac{a^{2n+1}}{2^{2n+1}(n+1)!n!}}{\sum_{n=0}^{\infty}\frac{a^{2n}}{2^{2n}n!n!}}\quad\text{and}\quad\langle\cos\varphi\rangle_{3D}^{H\to 0}=\frac{\sum_{n=0}^{\infty}\frac{2a^{2n+1}}{(2n+1)!(2n+3)}}{\sum_{n=0}^{\infty}\frac{2a^{2n}}{(2n+1)!}}. \tag{8}$$

At high external field in (2) the coth(a) tends to 1 and performing the Taylor expansion in (3) when a tends to infinity the magnetization formulas lead to [3]:

$$\langle\cos\varphi\rangle_{2D}^{H\to\infty}=1-\frac{1}{2a}-\frac{1}{8a^2}-\frac{1}{8a^3}-\frac{25}{128a^4}-\cdots\quad\text{and}\quad\langle\cos\varphi\rangle_{3D}^{H\to\infty}=1-\frac{1}{a}. \tag{9}$$

1.2. Dipole as a linear pendulum

The equation of the magnetic dipole motion put into a static magnetic field is [4,5]:

$$\Theta\ddot{\varphi}+mH\sin\varphi=0, \tag{10}$$

where Θ is the moment of inertia calculated to the axis of symmetry of the dipole. After linearising this equation the natural frequency of the undamped, unexcited vibrational system is:

$$\omega_0=\sqrt{mH/\Theta}. \tag{11}$$

This natural frequency applies to the real vibrational motion when the φ_0 amlitude is smaller than approximately 1°. Without linearising (10) the expressions $\varphi(t)$ and $\dot{\varphi}(t)$ are pretty complicated [4,5].

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1.3. The Maxwell-Boltzmann distribution to the angular velocity

The rotational energy of particles follows the Maxwell-Boltzmann distribution [6]. In 2D the rotational degree of freedom of a dipole is one, in 3D it is two, hence the probability density functions of the angular velocity are:

$$f_{\dot{\varphi}} = \frac{c}{Z} exp\left(-\frac{N^2}{2\Theta k_B T}\right) \quad (2D) \qquad \text{and} \qquad f_{\dot{\varphi}} = \frac{c}{Z} exp\left(-\frac{N_x^2+N_y^2}{2\Theta k_B T}\right), \quad (3D) \tag{12}$$

where Z is the partition function, c is a normalizing constant, and N signals the angular momentum. Performing the integrals and transformations, density functions of the angular velocity can be written as

$$f_{\dot{\varphi}} d\dot{\varphi} = \left(\frac{2\Theta}{\pi k_B T}\right)^{1/2} exp\left(-\frac{\Theta\dot{\varphi}^2}{2k_B T}\right) d\dot{\varphi} \quad (2D) \qquad \text{and} \qquad f_{\dot{\varphi}} d\dot{\varphi} = \frac{\Theta}{k_B T}\dot{\varphi} exp\left(-\frac{\Theta\dot{\varphi}^2}{2k_B T}\right) d\dot{\varphi}. \quad (3D) \tag{13}$$

The maximum of the function in 2D is at zero, while in 3D the value is zero at zero (see Fig. 1).

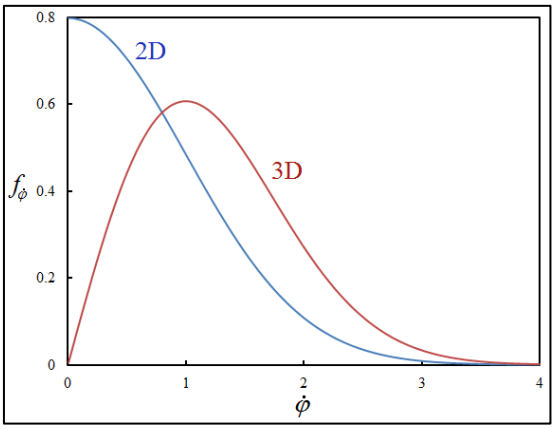

Figure 1. The curves of Maxwell-Boltzmann distribution of angular velocity distribution when the degree of freedom in 2D is one, in 3D is two $(\boldsymbol{\Theta/k_B T = 1})$

2. MAGNETIZATION FROM PENDULUM MOTION

According to the equipartition theorem, the average kinetic energy of a particle per degree of freedom is $k_B T/2$. Taking into account the number of the rotational degree of freedom in 2D and 3D, respectively, this yields:

$$\frac{1}{2}\theta\langle\dot{\varphi}^2\rangle = \frac{1}{2}k_B T \quad (2D) \qquad \text{and} \qquad \frac{1}{2}\theta\langle\dot{\varphi}^2\rangle = \frac{2}{2}k_B T. \quad (3D) \tag{14}$$

Nevertheless, supposing that the dipole is doing harmonic rotational motion [7] taking effect from the external magnetic field, the relation between the average and maximum value of angular velocity is $\langle\dot{\varphi}^2\rangle = \dot{\varphi}_{max}^2/2$. Using the expression $\dot{\varphi}_{max} = \varphi_0\omega_0$ for the amplitude of vibrational motion leads to

$$\varphi_0 = \sqrt{\frac{2kT}{\omega_0^2\theta}} = \sqrt{\frac{2}{a}} \quad (2D) \qquad \text{and} \qquad \varphi_0 = \sqrt{\frac{4kT}{\omega_0^2\theta}} = \sqrt{\frac{4}{a}}. \quad (3D) \tag{15}$$

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It is worth to note that the same results are got to take notice as a starting point of the calculation the vibration energy instead of kinetic energy. In this way

$$\frac{1}{2}s_t\langle\varphi^2\rangle = \frac{1}{2}k_BT \quad \text{(2D)} \qquad \text{and} \qquad \frac{1}{2}s_t\langle\varphi^2\rangle = \frac{2}{2}k_BT, \quad \text{(3D)} \tag{16}$$

where $s_t = mH$ is the torsion spring rate and the relation between the average angular displacement value and aplitude is $\langle\varphi^2\rangle = \varphi_0^2/2$. Consequently the dipole has a motion around the equilibrium position with φ_0 amplitude and ω_0 natural frequency (equilibrium position means that the angle between dipole and external field is zero): $\varphi(t) = \varphi_0 \sin(\omega_0 t)$. The period of oscillation is $T_p = 2\pi/\omega_0$. The non-interacting magnetization value from the timing average of the external field directional component of dipole moment:

$$\langle\cos\varphi\rangle = \frac{1}{T_p}\int_0^{T_p}\cos(\varphi_0\sin(\omega_0 t))\,dt. \tag{17}$$

Performed the expansion of cosine function appear only even powers of sinus function. It is known that

$$sin^n x = \frac{1}{2^n}\binom{n}{\frac{n}{2}} + \frac{2}{2^n}\sum_{k=0}^{\frac{n}{2}-1}(-1)^{\left(\frac{n}{2}-k\right)}\binom{n}{k}\cos\big((n-2k)x\big), \tag{18}$$

where n is an even number. The second term of this expression vanishes performing the integral (17) to the whole period. Thus the following simple formula is obtained for the average angular displacement, which is valid for both 2D and 3D:

$$\langle\cos\varphi\rangle = \sum_{n=0}^{\infty}(-1)^n\frac{\varphi_0^{2n}}{2^{2n}n!^2}, \tag{19}$$

and using (15) the expansions of non-interacting magnetization function are:

$$\langle\cos\varphi\rangle_{2D} = \sum_{n=0}^{\infty}(-1)^n\frac{1}{(2a)^n n!^2} = 1 - \frac{1}{2a} + \frac{1}{16a^2} - \frac{1}{288a^3} + \cdots, \tag{20}$$

$$\langle\cos\varphi\rangle_{3D} = \sum_{n=0}^{\infty}(-1)^n\frac{1}{a^n n!^2} = 1 - \frac{1}{a} + \frac{1}{4a^2} - \frac{1}{36a^3} + \cdots. \tag{21}$$

The first two terms equal to the first two terms in (9), thus one can say that at high mH/k_BT, where the linearising of (10) is valid, (20) and (21) reproduce the results of the basic theory.

3. THE NEGATIVE MAGNETIZATION

According to (13) the Maxwell-Boltzmann distribution is able to apply to the angular velocity of dipoles. The angular velocity on x axes on Fig. 1 corresponds to the time average of angular velocity: $\langle\dot{\varphi}_i\rangle$. The amplitude which belongs to a given $\langle\dot{\varphi}_i\rangle$ average angular velocity:

$$\varphi_{0i} = \dot{\varphi}_{i,max}/\omega_0. \tag{22}$$

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The average angular velocity is different according to Fig. 1 but the natural frequency and the period is the same for all dipoles at a given temperature. The relation between maximum and average angular velocity referring to a dipole which has a given $\langle\dot{\varphi}_i\rangle$ average angular velocity is:

$$\langle\dot{\varphi}_i\rangle = \frac{2}{\pi}\dot{\varphi}_{i,max}. \tag{23}$$

Consequently the amplitude:

$$\varphi_{0i} = \frac{\pi}{2}\langle\dot{\varphi}_i\rangle/\omega_0. \tag{24}$$

Using this expression in (19) the magnetization denoted by $\langle\dot{\varphi}_i\rangle$ average angular velocity is: $\langle\cos\varphi\rangle_i$. On Fig. 2 the values of $\langle\cos\varphi\rangle_i$ are shown as a function of $\langle\dot{\varphi}_i\rangle$ at the values of three different $a = mH/k_BT$. When $\langle\dot{\varphi}_i\rangle \to +0$ the average angular displacement $\langle\cos\varphi\rangle_i \to 1$. Increasing the average angular velocity the aplitude increases and the average angular displacement can turn into the negative zone. The dashed lines sign when the amplitude is greater than π, thus the linearized equation of motion (10) is not valid yet, because in this case the vibrational motion turn into rotational motion with altering angular velocity. Nevertheless the negative magnetization effect appears somewhere the aplitude is greater than π/2 and less than π, and exists when rotational motion occurs. Hence the positive values of the dashed lines on Fig. 2 are necessarily incorrect.

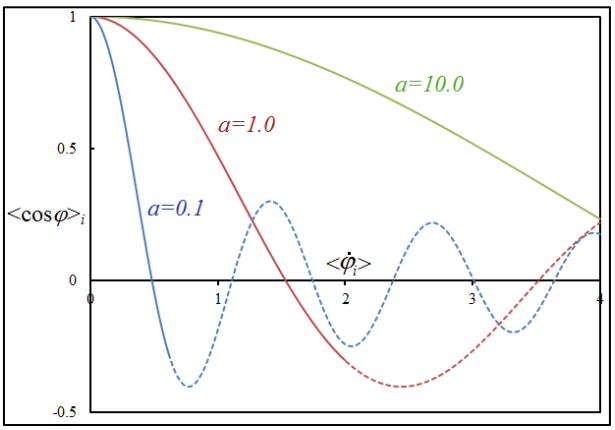

Figure 2. The average angular displacement as a function of the average angular velocity at three different values of mH/k_BT

The total magnetization from summation part magnetizations weighted by the Maxwell-Boltzmann distribution can be written as (see (13) and (19)):

$$\langle\cos\varphi\rangle = \int_0^\infty f_{\dot{\varphi}}\,\langle\cos\varphi\rangle_i d\dot{\varphi}. \tag{25}$$

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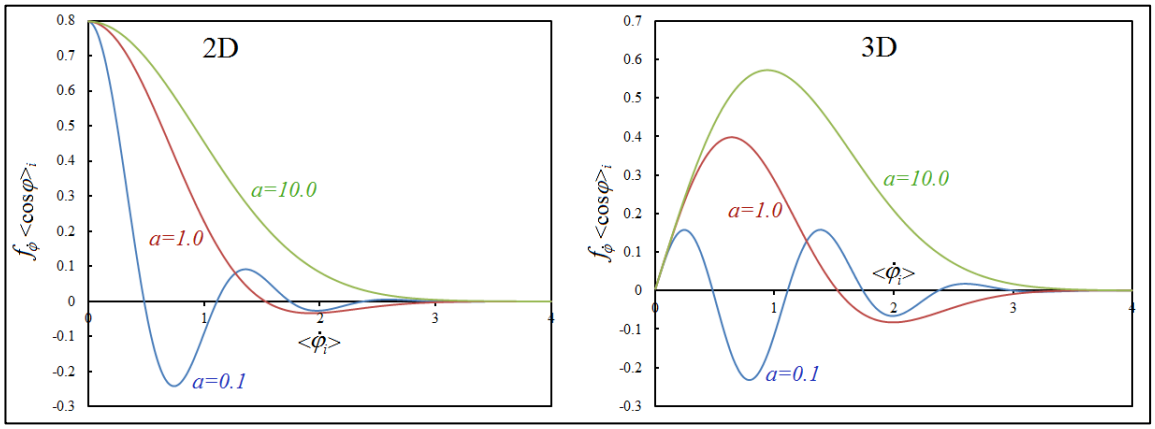

Figure 3. The average angular displacement weighted by the Maxwell-Boltzmann distribution as a function of the average angular velocity at three different values of mH/k_BT. The total magnetization is come from the integration of these functions

On Fig. 3 the curves of part magnetizations are shown in 2D and 3D at three different values of $a = mH/k_BT$. It seems when a is large the all particles have a positive part magnetization. The magnetization of non-interacting fluidum comes from the integration of Maxwell-Boltzmann distribution weighted part magnetizations.

4. CONCLUSION

In this paper the Taylor expansion expressions of magnetization of the non-interacting dipoles has been calculated in 2D and 3D on the basis of the vibrational model. The temperature was taken notice with the help of the equipartition theorem which provided the amplitude and the natural frequency of harmonic oscillation. Calculating the average of cosine value of angular excursion a compact formula was arisen for the independent, non-interacting magnetization. Due to the linearising of differential equation, the agreement between our theory and the exact formula is satisfactory only at high external field. Applying the Maxwell-Boltzmann distribution at angular velocity of dipoles, the results have shown that in a non-interacting fluidum exist such particles which have negative magnetization. The main limit of the presented vibrational model is the linearising of (10). In the future an attempt will be made to perform the calculations without linerisation.

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